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GEOLOGY
OF
SALT DOME OIL FIELDS

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A SYMPOSIUM ON THE ORIGIN, STRUCTURE, AND GENERAL GEOLOGY OF SALT DOMES, WITH SPECIAL REFERENCE TO OIL PRODUCTION AND TREATING CHIEFLY THE SALT DOMES OF NORTH AMERICA

By

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PREFATORY NOTE

The Program Committee for the Meeting of the American Association of Petroleum Geologists at Houston, Texas, in March, 1924, strove to present to visiting geologists a comprehensive picture of American salt domes, and to collect and record in permanent form the information that has accumulated during twenty years of exploration for petroleum around the salt domes of the Gulf Coastal Plain. The original plan included a brief, accurate description of each of the known salt domes. The results of that effort appear on the following pages. Although the list is not yet quite complete, the facts concerning a number of typical salt domes are presented with sufficient detail to portray adequately the true nature of this remarkable type of geologic structure. Along with these descriptive papers, and based largely on the data contained in them, are several theoretical and interpretative studies, together, also, with some discussion of European salt domes.

Much past speculation as to the origin of salt domes, especially in America, appears to be unsound, and the error results from an inaccurate or distorted conception of the true form and character of our salt domes. It is hoped that with a more accurate, more detailed picture of American salt domes, such as this volume attempts to present, students of salt-dome origin may clarify and bring into accord their several theories. That this body of facts may be more readily and more conveniently available to students of salt-dome geology, the various papers which have been published currently in the *Bulletin* are now brought together in a single volume.

To the authors of the various manuscripts is due the credit for whatever merit may attach to this effort. The burden of editing has devolved largely upon the Association's regular editor, Mr. Raymond C. Moore. Mr. Donald C. Barton and Mr. Alexander Deussen assisted the undersigned in the collection, criticism, and preliminary editing of the manuscripts.

WALLACE E. PRATT

HOUSTON, TEXAS

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ORIGIN OF NORTH AMERICAN SALT DOMES

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ABSTRACT

A critical review of American thought on salt-dome origin shows that from the discovery of American salt domes in 1862 until the establishment of their economic importance by the development of a cap-rock pool at Spindletop in 1901, little was known of the constitution of the domes except what little was expressed at the surface. The result was a wide variety of highly speculative theories of origin, chief of which, as best fitting our meager knowledge, was the theory that the domes were old Cretaceous islands in Tertiary and even Recent seas.

Exploration of the known domes for cap-rock pools and sulphur deposits from 1901 to 1916–18 made us better acquainted with the salt, anhydrite, gypsum, limestone, sulphur, and various minor minerals—the salt-dome materials—and theories of deposition from solution became the vogue.

The development of important oil deposits in the lateral sands flanking the salt masses, from 1912 to date, concentrated attention on the structural features of the dome. The deposition-from-solution and lifting-power-of-crystallization theories seemed to be inadequate to explain the sharp and considerable uplift caused by the formation of the salt core and cap rock, and, with a growing recognition of the similarity of American salt domes to the salt structures of Germany, Roumania, Mexico, and elsewhere, came a gradual swing to the theory of tectonic origin.

This theory of tectonic origin supposes that the plastic salt was forced by pressure to flow from originally bedded deposits into its present position.

The author accepts the tectonic or pressure-flowage theory for the origin of American domes and believes that the most serious objection raised by its opponents—the lack of evidence as to the existence of sedimentary salt deposits—is no longer tenable in view of the recent discovery of potash salts and fossil algae in the salt core of the Markham dome.

INTRODUCTION

Great bosses and ridges of rock salt, differing from the more ordinary forms of bedded deposits, are known to occur in various areas of sedimentary rock throughout the world. These interesting salt masses, which, for lack of a better term broad enough to include all varieties, may well be called "salt structures," are found in two regions of the North American continent: the Texas-Louisiana and Isthmus of Tehuantepec regions.

The Texas-Louisiana occurrences are of the plug or boss type generally called "salt domes." It is the purpose of the present paper to review the development of theories to account for the formation of this particular type of salt structure and to suggest what appears to the writer to be the most acceptable theory of origin.

A salt structure consists essentially of an anticline with a salt core, the structure of the enveloping rocks resulting in whole or part from the formation of the core. A salt dome is a very special form of salt structure having a circular or elliptical plane section.

The general use of the term "salt dome" is not entirely satisfactory except in the United States. "Salt anticline," "salt structure," or some similar term would seem to be more suitable for general application. The long salt ridges or anticlines of Mexico and Germany are in no sense domes, though apparently of similar origin, but it so happens that all of the salt structures known to date in the United States are true salt domes or salt plugs.

A salt structure consists essentially of the salt core, with or without cap rock, both of which are salt-structure material, and of the enveloping or abutting country rock to the extent to which its structure has been affected by the forces giving rise to the intrusion of the salt core.

The cores range in size and shape from shallow and flat to sharp and sometimes overturned ridges, miles in length, as in many of the European and Mexican structures; and from sharp to flat-topped conical plugs, of circular plane section, such as are so characteristic of the Gulf Coastal plain of the United States and of less common occurrence elsewhere.

The salt core may or may not be accompanied by a cap of massive anhydrite, or gypsum, limestone, dolomite, or of combinations of these with various minerals of minor importance including sulphur, selenite, calcite, galena, sphalerite, barite, pyrite, petroleum, etc. This cap rock of the coastal region—the *Gypshut* of the Germans —may be only a few feet or several hundred feet in thickness, and may be perched upon the top of the salt core, like the tip on a billiard cue, as is common in the domes of the United States, or extend, thimble-fashion, down its sides, as in certain of the German and Mexican structures.

The structure of the sedimentary rocks overlying and adjacent to the salt and cap-rock core, when not complicated by faulting of independent importance and considerable magnitude, is apparently that caused by displacement sufficient to accommodate the intrusion of the salt and cap-rock core. The sedimentary rocks usually dip away from the salt.

The true salt dome is apparently an extreme or mature form of salt anticline, a conclusion which the writer is pleased to note is also put forward by Stille for German domes.

Salt structures are known to occur, outside of North America, in the general region of the Harz Mountains and the North German plain; on the south flank of the Carpathians and in the Transylvania Basin in Roumania; on the shores of the Red Sea in Egypt; in Southern Persia; and in Russia, Spain, Algeria, and Morocco. No occurrences have been described from South America though Pogue[1] calls attention to a possible salt structure in Colombia.

The two known salt structure regions in North America, one in the Texas-Louisiana province and the other in the Isthmus of Tehuantepec, Mexico, both lie within the coastal plain of the Gulf of Mexico.

As a speculation, it is suggested that salt structures will be found to be of much more common occurrence than is indicated by this catalogue. The type of structure is familiar to but few geologists and, lacking exploration by drill or shafts, may often be indistinguishable from other and more ordinary types of structure. A recently described salt deposit at Malagash, Novia Scotia,[2] has all the earmarks of a salt structure, but not enough is yet known to classify it definitely.

The better-known and more extensive Texas-Louisiana province includes two groups of domes. The coastal group occurs in the very flat lands of the coast along a strip extending inland about 70 miles from the Gulf cf Mexico and from just west of the Mississippi to a short distance south of the Rio Grande. The interior group lies on the east flank of the Sabine uplift in northwestern Louisiana and in the syncline just west of the Sabine uplift in northeastern Texas. The interior group, as known at present, lies about 100 miles north of the coastal group. It might be subdivided into the Louisiana interior and the Texas interior groups, since these are separated by the Sabine uplift and lie some distance apart. Further study may indicate that this subdivision is of geologic as well as geographic importance.

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[1] J. E. Pogue, *Trans. Amer. Inst. Min. Eng.*, Vol. 65 (1921), p. 324.

[2] A. O. Hayes, "The Malagash Salt Deposit, Nova Scotia, Canada," *Dept. of Mines Geol. Surv., Memoir 121*, Ottawa, 1920.

The Isthmus of Tehuantepec province lies in the southeasternmost cantons of the state of Vera Cruz, Mexico, within a radius of 50 miles from the village of Minatitlan. It is much smaller in size than either the interior or coastal groups and is entitled to classification as a province only because it is an independent area and has an individual history and definite characteristics of its own.

The Texas-Louisiana domes are coming to be comparatively well known. The coastal group are but slightly expressed by surface geology, but are usually marked by a striking, if slight, topographic expression. They have been extensively explored by drill holes and mining operations. The interior domes are usually well expressed geologically and topographically, but have not been so extensively explored by the drill as have the domes of the coastal group.

The Tehuantepec salt structures are excellently expressed at the surface, both geologically and topographically. They have not been drilled so extensively as have the Texas-Louisiana domes, but the drilling has generally been more carefully directed and observed. In time, the study of the Tehuantepec area should yield more definite results than the study of the Texas-Louisiana area. The structures are better expressed at the surface.

AMERICAN THOUGHT ON SALT-DOME ORIGIN

The origin of salt domes has been a fruitful subject for controversy with American geologists since Thomassey, in 1860, first described the Five Islands and launched into the seas of speculation with his suggestion of volcanic origin. Much has been written and more has been said, often by men having at best an entirely inadequate knowledge, of the all too meager store of fact available to us regarding these interesting structures.

The development of American theories of salt-dome origin may be divided conveniently into three periods. The first period, extending to the time of the discovery of oil at Spindletop in 1901, was a time of casual theories, when next to nothing was known about the real constitution of the domes. Interest in them was casual and desultory and, as is always the case when exact information is too scarce to limit imagination seriously, widely different theories of origin were promulgated. Since the chief test for excellence in theory is that it shall not violate known fact, it is not surprising that a wide variety of theories should have been put forward.

The second period, marked by deposition from solution theories, extends from the determination of the great economic importance of these domes by the discovery of oil at Spindletop in 1901 to about 1916–18. The theories most favorably received were those attributing the origin of the domes to deposition from solution. This was the period of the development of the cap-rock pools and of development of the sulphur mines in the cap rock of the domes. Drilling operations added greatly to our knowledge of the domes, but the additions had largely to do with salt-dome material—the salt, limestone, gypsum, anhydrite, sulphur, and various minor minerals. Information as to the structure of the contiguous sediments was not entirely lacking, but much of it was presumptive evidence. The bulk of additions as to fact, and those most stressed, were observations regarding character, extent, and position of the dome materials—materials whose origin could most easily be explained by theories of deposition from solution.

The third period, which is one of structural theories, extends from 1916–18 down to the present. About 1914, exploration of the cap-rock areas of the known domes being practically complete, the rapid diminution of their economic importance was checked and interest in the domes was revived by the discovery of important oil deposits in the lateral sands flanking the salt masses. Salt domes which had been regarded as practically exhausted were rejuvenated as potential oil fields, and we are still in the period of exploring the flanks of the old domes as well as searching for new ones. The knowledge of domes which has been developed as a result of this campaign has had to do mainly with the structure of the sedimentary rocks enveloping the salt and cap-rock mass. This information accents chiefly the upthrust which has been occasioned by the formation of the salt plug, and it is not surprising to see opinion trend to the theories of tectonic origin since they seem best to explain such structure.

Through all of these periods, like the chorus in a Greek tragedy, run constantly recurring theories of dome-origin as a result, direct or indirect, of volcanic activity. The theory of volcanic origin has never been generally accepted, has perhaps never even been adequately set forth, and, in the absence of some direct evidence of volcanic activity, seems to the writer to be more speculative than most other theories. It has, however, received favorable comment from many of the men best equipped, by an intimate knowledge of salt domes, to deal with the subject, and it can by no means be definitely and finally discarded.[1]

FIRST PERIOD (1860–1901); CASUAL AND RANDOM THEORIES

The main mass of rock salt at Petite Anse, Five Islands, was discovered during the deepening of one of the old brine wells in May, 1862. This was our first step toward a knowledge of the real structure of a North American salt dome.

The salt springs which are so often associated with the domes had been known to the early settlers and to the Indians, and had served as sources of brine for salt manufacture. Coxe,[2] in the early part of the eighteenth century, evidently referred to the salines of northern Louisiana in the statement: "There are many springs, pits and lakes, which afford most excellent common salt in great plenty, wherewith [the Indians] trade with neighboring nations for other commodities they want." Stoddard[3] notices and describes one of the Five Islands.

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[1] The writer has reviewed the theory of volcanic origin critically with unfavorable conclusions. See E. DeGolyer, "Theory of Volcanic Origin of Salt Domes," *Trans. Amer. Inst. Min. Eng.*, Vol. 61, pp. 456–69. New York, 1919.

[2] Daniel Coxe, A description of the English province of Carolina, by the Spaniards called Florida and by the French, La Louisiane, etc., 2d ed., London, 1726. Requoted from Harris and Veatch, *Historical Review*. A preliminary "Report on the Geology of Louisiana," *Geol. Surv. of Louisiana, Report for 1899, Baton Rouge*, which see for early references.

[3] Major Amos Stoddard, *Sketches, Historical and Descriptive of Louisiana*. Philadelphia, 1812.

He notes with regard to these islands that "some of them are impregnated with sulphur and one of them has been known to be on fire for at least three months." Travelers' tales! Darby[1] evidently visited Drake's and Bisteneau domes and described Petite Anse. He indulged in the first vague speculation as to origin, attributing the islands to a source other than "the revolution affected by alluvion."

Thomassy,[2] who visited the Five Islands in 1857 and 1859, describing them with some care, noting their similarity, alignment, and distinct characteristics, apparently suspected the presence of rock salt. After the discovery of the salt mass, he again visited Petite Anse,[3] and in announcing the finding of the salt, he reaffirmed the theory of volcanic origin, announced in his earlier work, "in the sense that it [Petite Anse] comes from a volcano of water, mud, and gas," and that the rock salt was formed from the evaporation of sea water by volcanic heat. Thomassy was impressed by the symmetry of the mounds and regarded the ponds found on them as being extinct crater types. He regarded the domes as akin to the mud lumps of the Mississippi delta and believed that he detected evidence of corrosion by thermal and acid waters on certain rocks found near Petite Anse which he supposed had been ejected from the depth of the gulf through explosive action.

Richard Owen,[4] while stationed with the Federal Army at New Iberia, in 1865, studied Petite Anse cursorily and concluded that the island was not of volcanic origin but that the salt was produced by the evaporation of sea water in barrier lagoons.

Goesmann,[5] in 1867, reported on the Petite Anse deposit. He rejected Owen's salt-plan theory and suggested that the salt resulted from the evaporation of brine springs rising through older deposits of bedded salt—a theory very similar to the later and more elaborate theories of Hill and Harris.

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[1] William Darby, *A Geographical Description of the State of Louisiana, etc.* Philadelphia, 1816.

[2] R. Thomassy. *Geologie pratique de la Louisiana.* Paris, 1860.

[3] R. Thomassy, "Supplement *à* la geologie pratique de la Louisiana, Île Petite Anse," *Societe Geologique de France, Bull. 20* (2d series, 1863), pp. 542–44.

[4] Richard Owen, "Report on Quaternary Rock Salt Deposits in Louisiana," *Trans. St. Louis Academy of Science*, Vol. 2 (1868), pp. 250–52.

[5] C. A. Goesmann and C. E. Buck, "On the Rock Salt Deposit of Petite Anse, Louisiana Rock Salt Co.," *Report of the American Bureau of Mines;* 35 pp., 2 pls. New York, 1867. Goesmann requoted from H. C. Bolton, *New York Academy of Science Trans.*, Vol. 7, pp. 124–25. New York, 1888.

Hilgard,[1] in 1867, examined this same deposit at the request of Joseph Henry, of the Smithsonian Institution. He published a number of papers from 1869 to 1882, in addition to the one noted. Before this study, he suggested that the salt had been formed in lagoons but afterward he concluded that Petite Anse was not of volcanic origin, but that the Louisiana domes and salines were Cretaceous outliers with cappings of drift and other alluvial material. The present topographic form of the domes he regarded as the result of erosion; the various outliers as peaks on an old Cretaceous range; and the age of the salt as Cretaceous. He thought that any abnormal dips at the surface of the domes were the result of differential settling and suggested a genetic relationship between Petite Anse and the Calcasieu sulphur deposit.

Hopkins,[2] in reporting on the geology of Louisiana, held to views similar to those of Hilgard. He regarded the salines and domes as peaks on an old Cretaceous ridge, the salt as of Cretaceous age, and in commenting upon the common association of limestone, gypsum, sulphur, and petroleum, regarded the minerals as resulting from the reactions between buried organic matter and gypsum.

Lockett,[3] in 1870, visited the Five Islands. He considered them merely as the continuation of the Cote Gelee, Carenero, Grande

[1] E. W. Hilgard, "On the Geology of Lower Louisiana and the Salt Deposits of Petite Anse Island, "*Smithsonian Contributions, Separate No. 248*, pp. 32–34. Washington, 1872.

[2] F. V. Hopkins, *First Annual Report of the Louisiana State Geological Survey; Annual Report of Board of Supervisors of the Louisiana State Seminary of Learning and Military Academy for the Year Ending Dec. 31, 1869*, pp. 77–109. New Orleans, 1870; *Second Annual Report of the Geological Survey of Louisiana to the General Assembly; Annual Report of the Board of Supervisors of the Louisiana State University for the Year Ending Dec. 31, 1870*, pp. 1–7. New Orleans, 1871; *Third Annual Report of the Geological Survey of Louisiana; Annual Report of D. F. Boyd, Superintendent Louisiana State University for 1871*, pp. 163–206. New Orleans, 1872.

[3] Colonel Samuel H. Lockett, *Report of the Topographical Survey of Louisiana, Louisiana State University; Report of Superintendent for 1870*, pp. 16–26. New Orleans, 1871.

Coteau, and Opelousas Hills; the whole at one time forming a great natural levee along the shores of an estuary occupying the Mississippi Valley. During a great flood a series of mighty crevasses were made in this levee, and thus the islands were formed.

Penrose,[1] in 1889, examined the Palestine dome, identified the outcrop of Cretaceous rocks and concluded that it "doubtless represents the remains of an island in the old Tertiary sea."

Herndon[2] described Books and Steen salines and regarded the former as an old Cretaceous island in the Tertiary seas.

Dumble[3] examined the Palestine dome in 1890. He regarded it as "only one of a series of these deposits of salt which seem to extend in two or more lines from northeast Texas in a southeasterly direction toward the Gulf." He lists all of the Texas interior group of salt domes which we know today except Keechi, and concludes that "they represent islands in the Tertiary sea formed by projecting eminences of the underlying strata of Cretaceous age."

Kennedy,[4] in 1892, described Grand Saline and seems to have escaped the idea, then orthodox among members of the Texas Geological Survey, that it was a Cretaceous outlier. He describes the dip of the rocks in some detail and refers to it as the "Grand Saline fold."

Lerch, in 1893, set forth the results of his observations of the geology, including that of the salines, in north Louisiana. In the first of his papers[5] he concludes that no volcanic eruptions and no violent contortions have disturbed the geological formations of north

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[1] R. A. F. Penrose, "A Preliminary Report on the Geology of the Gulf Tertiary of Texas from the Red River to the Rio Grande," *First Annual Report, Geol. Surv. Texas* (1889), p. 101. Austin, 1890.

[2] J. H. Herndon, "Smith County (the Iron Ore District of East Texas)," *Second Annual Report Geol. Surv. Texas* (1890), pp. 222–24. Austin, 1891.

[3] E. T. Dumble, "Anderson County (the Iron Ore District of East Texas)," *ibid.*, pp. 303–17.

[4] William Kennedy, "A Section from Terrell, Kaufman County, to Sabine Pass on the Gulf of Mexico," *Third Annual Report Geol. Surv., Texas* (1891), pp. 41–125. Austin, 1892.

[5] Otto Lerch, "A Preliminary Report upon the Hills of Louisiana, North of the Vicksburg, Shreveport, and Pacific Railroad, Louisiana State Experiment Stations," *Geology and Agriculture*, Vol. 1 (1893), p. 27.

Louisiana; and in a second paper,[1] after stating that the existence of salines can only be traced along the summit of a Cretaceous ridge, which traverses the state diagonally from its northwest corner to the island of Petite Anse, arrives at a conclusion combining Hilgard's Cretaceous outlier theory and a theory similar to volcanic origin. It was his idea that at the close of Mesozoic time enormous plutonic forces had thrown up mountain chains of vast extent and that isolated peaks in the ranges so formed had been islands in the Tertiary sea. He also regarded the Balcones fault and the basaltic outbreaks along it as of contemporaneous origin.

Vaughan,[2] in 1895, in publishing the report of his own work in Louisiana, reviewed the papers of Hilgard and Lerch and expressed conformity with Hilgard's idea of a Cretaceous ridge. He failed to observe evidences of any orogenetic movement as postulated by Lerch.

Clendenin,[3] as a result of investigations during the summers of 1894–95, expressed the opinion with regard to Thomassy's theories that there was no evidence of volcanic activity. He followed Hilgard, whom he quotes extensively, but suggested, somewhat after Lerch, that the Cretaceous outliers are the result of differential elevation rather than differential erosion. He recognized clearly the earth movement during comparatively late geological time.

Harris and Veatch,[4] in 1899, published the first considerable studies of the Louisiana domes and salines. They regarded the Five Islands as "a series of very peculiar dome-shaped folds and, to all appearances, a large fault," formed in Quaternary or Recent time. The Cretaceous outcrops of northern Louisiana are regarded as "similar domes," but it "is hard to believe they were formed so recently" as the Five Islands. The Winnfield anticline indicates that part of the movement at least was post-Claiborne. They concluded against Hilgard's Cretaceous ridge and in favor of "northeast-southwest local folds parallel to old shorelines" to account for the domes.

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[1] "A Preliminary Report upon the Hills of Louisiana, South of Vicksburg, Shreveport, and Pacific Railroad to Alexandria, Louisiana, Louisiana State Experiment Stations," *ibid.*, Vol. 2, 53–109.

[2] T. Wayland Vaughan, "Stratigraphy of Northwestern Louisiana," *Amer. Geol.*, Vol. 15 (1895), pp. 208–29.

[3] W. W. Clendenin, "A Preliminary Report upon the Florida Parishes of East Louisiana and the Bluff, Prairie, and Hill Lands of Southwest Louisiana, Louisiana State Experiment Stations," *Geology and Agriculture*, Vol. 3 (1896), pp. 236–40.

[4] Gilbert D. Harris and A. C. Veatch; "A Preliminary Report on the Geology of Louisiana Geological Survey of Louisiana," *Report for 1899*, pp. 9–138. Baton Rouge.

Veatch,[1] in 1899, left off his study of the salines of north Louisiana to investigate the Five Islands. He reports that only two of the islands show indications of method and date of origin, Belle Isle showing a very distinct dome-shape fold and Petite Anse seeming to represent a fault block. He regarded the supposed faulting as possibly due to solution of the underlying salt, but more likely due to orographic movement. He concluded that the formations of the island possibly began with movement in late Tertiary time, evidence of which had thus far been seen only at Petite Anse; that the main folding and faulting occurred in the Pleistocene and was followed by the sinking of the whole coastal region and deposition of the upper yellow clays; that during a succeeding period of elevation, the deep channels of the coastal rivers were excavated and lake valleys formed in the island; and the subsidence which followed had continued to the present day.

Anthony F. Lucas, in 1896, discovered salt under Jefferson Island and thus initiated the most fruitful part of the prospecting and study of the coastal domes which culminated in his discovery of the Spindletop gusher in January, 1901. In 1896, in 1898, and in 1899 he published papers[2] on Louisiana salt, but was concerned with occurrence rather than origin, merely noting a belief that the geological formations of the Five Islands is Quaternary, that the salt is of Tertiary age, and appears to rest on the Cretaceous, and that the salt formation at Jefferson Island does not lie in undisturbed strata but seems to have been folded and contorted while still in a plastic condition. Lucas clearly recognized the dome structure of Spindletop, but is said to have thought it was due to gas pressure.[3]

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[1] A. C. Veatch, "The Five Islands, Louisiana, Louisiana State Experiment Stations," *Geology and Agriculture*, Vol. 5 (1899), pp. 259–60, pls. 19–31.

[2] A. F. Lucas, "The Avery Island Salt Mine and the Joseph Jefferson Salt Deposit, Louisiana," *Eng. and Min. Jour.*, Vol. 62 (1896), pp. 463–64; "Louisiana Salt Resources," *American Manufacturer*, Vol. 63 (1898), pp. 910–11; "Rock Salt in Louisiana," *Trans. Amer. Inst. Min. Eng.*, Vol. 29 (1899), pp. 465–66.

[3] Robert T. Hill, "The Coast Prairie of Texas," *Science*, N.S., Vol. 14 (1901), p. 327.

Veatch,[1] in reporting on the salines of north Louisiana, expressed no substantial modification of his views as expressed for the Five Islands. He seems to have become quite definitely convinced of the anticlinal or domelike structure of the sedimentary rocks surrounding the salt cores; he recognized clearly the similarity of the coastal domes, both in Texas and Louisiana to the northern salines; and he published the first general Texas-Louisiana map showing an alignment of the domes.

Adams,[2] in 1901, after the discovery of Spindletop, published a preliminary report indicating many of the interior group of domes, which he maps as Cretaceous outliers, and lists many of the coastal domes as being prospected for oil. His paper does not show that he recognizes these occurrences as salt domes, though he states that Petite Anse and Grand Saline are probably similar types. He regards the salt as probably of Cretaceous age and republishes the F. V. Hopkins section through Petite Anse, Pine Prairie, and Winnfield.

SECOND PERIOD (1901–16); DEPOSITION FROM SOLUTION THEORIES

The theory of Goesmann was the first of the deposition from solution theories of salt-dome origin to be put forward, but it was promulgated at a time when the salt dome was little known and of almost no general interest. With the discovery of the Lucas gusher at Spindletop, however, and the completion of a survey of the Louisiana domes by Veatch, the domes began to receive more serious attention from geologists.

Harris[3] visited Spindletop shortly after the discovery and announced that the scanty evidence available indicated that the Lucas gusher was on a Cretaceous anticline, a theory which he regarded as corroborated by the log of the Higgins well.[4]

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[1] A. C. Veatch, "The Salines of North Louisiana," *Geol. Surv. of Louisiana, Report of 1902*, pp. 47–100.

[2] George I. Adams, "Oil and Gas Fields of the Upper Cretaceous and Tertiary Formations of the Western Gulf Coast," *U. S. Geol. Surv. Bull. 184*, pp. 37–62. Washington, 1901.

[3] G. D. Harris, communication to *New Orleans Picayune*, March 27, 1901. Requoted from Harris, "Oil in Louisiana," *Geol. Surv. of Louisiana, Report of 1902*, p. 273.

[4] G. D. Harris, "Oil in Texas," *Science*, N.S., Vol. 13 (April 26, 1901), pp. 666–67.

Hill[1] at first thought that there was no structural disturbance and that wells might be drilled "with reasonable assurance that oil is apt to be found anywhere within the region of the coast plain above the oil-impregnated sands." He concluded "that oil should be found at decreasing depths at the rate of about seven to ten feet per mile along the line drawn from Beaumont to Oil City, in southern Nacogdoches County." After a visit to Damon Mound, however, he was convinced by Lucas that Spindletop was a true dome,[2] though he regarded the domes as "probably due to isostatic movements rather than accumulation of gas."

Hill, in 1902, published his theory on the formation of the domes by deposition from solution as follows:

> The oil and salt pockets of the Texas Coastal Plain are probably not indigenous to the strata in which they are found, but are the resultant products of columns of hot saline waters which have ascended, under hydrostatic pressure, at points along lines of structural weakness, through thousands of feet of shale, sand, and marine littoral sediments of the Coastal Plain section, through which oil and sand are disseminated in more or less minute quantities. The oil, with sulphur, may have been floated upward on these waters, and the salt and dolomite may have been crystallized from the saturated solution.
>
> The channels of these ascending waters may have been in places of structural weakness, such as fissures, which probably at one time continued to the surface, but may have been sealed by the deposition of the later overlapping strata now capping the oil pools.[3]

Hayes[4] reviewed Hill's theory, after making a study of the coastal region, and concluded that, while the theory was suggestive and worthy of careful consideration, it could not be accepted in its present form. By this time, the domelike structure of Spindletop had been definitely proved, and Harris,[5] on paleontological grounds, had determined a considerable uplift at Sour Lake.

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[1] Robert T. Hill, communication to *Times-Democrat,* May 29, 1901. Requoted from Harris, "Oil in Louisiana," *op. cit.*

[2] "The Coast Prairie of Texas," *Science,* N.S., Vol. 14 (1901), pp. 326–28.

[3] "The Beaumont Oil Field with Notes on the Other Oil Fields of the Texas Region," *Jour. of the Franklin Institute,* Vol. 154, pp. 273–74. Philadelphia, 1902.

[4] C. W. Hayes, "Some Facts and Theories Bearing on the Accumulation of Petroleum," abstract in *Science,* N.S., Vol. 16 (1902), p. 1028.

[5] G. D. Harris, "The Geology of the Mississippi Embayment," *Geol. Surv. of Louisiana, Report of 1902,* pp. 25 ff.

Coste,[1] in 1903, advanced the theory that salt domes are the result of "volcanic emanations bringing the water, salt, sulphur, oil, and gas from the interior in the state of vapors and gases, which condensed more or less near the surface, etc." He regarded the domes and salt masses as "the dying distant echo of that tremendous volcanic energy which, a little farther south, in Mexico, Central America and in the islands and along the southern coast of the Caribbean Sea, is to this day so powerfully active."

Hayes and Kennedy[2] had made a study of the Texas-Louisiana plain just after the completion of the Spindletop well in 1901. Their report, by far the most complete regarding salt domes which had yet been published, included a geological map of the area by Kennedy, a map of the coastal oil pools and prospects, indicating a northeast-southwest alignment, and noted the parallelism of this alignment with the Balcones fault. They regarded the domes as domal or anticlinal structures but as of a type wholly different from Appalachian structures, concluding that they "could scarcely have been produced by horizontal compression." They agree with the Harris assumption of an anticline at Spindletop, but state that it was of post-Eocene rather than Cretaceous age. While they state that "the mode of accumulation of the enormous masses of rock salt which occur in the Louisiana Salt Islands, in Damon Mound, in High Island, and also in Spindletop, has never been satisfactorily explained," they quote Hill's theory of origin, noting that it presents some serious difficulties, and conclude that it may be necessary "to refer their origin to supersaturated solutions coming through fissures opened along a fault line." In noting the alignment of the domes, they state that there has been "movement along these lines, including both flexing and faulting from as far back as Miocene into the present."

Hager, in 1904, presented an able paper summarizing the existing knowledge regarding the southern salt domes and proposed, in greater detail, a theory somewhat similar to that offered by Coste. Hager's theory is essentially as follows:

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[1] E. Coste, "The Volcanic Origin of Natural Gas and Petroleum," *Canad. Min. Inst. Jour.*, Vol. 6 (1904), pp. 73–123.

[2] C. W. Hayes and W. Kennedy, "Oil Fields of the Texas-Louisiana Gulf Coastal Plain," *U. S. Geol. Surv. Bull. 212*, 1903.

> By contact with the molten intrusives, vast quantities of gas were generated from the reduction of metallic sulphides and the distillation of lignites and organic substances. These gases, accompanied by steam under tremendous pressure, forced their way to the surface through the unconsolidated sands and clays of the overlying Tertiary material, perhaps giving rise to mud volcanoes, such as occur in many of the world's great oil fields at the present day. Heated waters from great depths found vent along the same channels, carrying in solution carbonates of lime and magnesium, gypsum and salt. By ebullition and evaporation these solutions became concentrated until, saturation resulting, precipitation commenced, forming the necklike masses of salt, gypsum and dolomite now encountered. With the cooling of the intrusive masses and the choking of the vents, the process practically ceased. A period of subsidence followed, during which the Coastal Quaternary beds, which at present cap the mounds, were laid down, followed by a secondary movement along the old lines of weakness, resulting in the present elevation of the mounds above the surrounding prairie.[1]

Hager admits that the weakness of his hypothesis lies in "the assumption of intrusives concerning the existence of which we have no evidence whatsoever," but finds some support for it in the occurrence of intrusive rocks and the upward displacement by them of overlying strata in the Austin, Texas, area as well as in the common occurrence of some form of vulcanism in most of the world's Tertiary oil fields.[2]

Fenneman studied the coastal domes in 1904 and in the preliminary statement of his work concludes with regard to their origin as follows:

> The mounds of the surface plainly owe their existence to some force exerted from beneath upward. It is inconceivable that any lateral pressure in these uncompacted Coastal Plain deposits should have resulted in approximately circular hills rising above the dead flat. It is too early to frame an exact hypothesis as to the nature of that force exerted from beneath, but indications in the field strongly suggest some association with an expansive force accompanying the crystallization of the minerals characteristic of such mounds.[3]

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[1] Lee Hager, "The Mounds of the Southern Oil Fields," *Eng. and Min. Jour.*, Vol. 78 (1904), pp. 137–39, 180–83.

[2] From his numerous citations of the occurrence of mud volcanoes in various oil fields, one must conclude that Hager regarded them as true volcanic phenomena.

[3] N. M. Fenneman, "Oil Fields of the Texas-Louisiana Gulf Coast," *U. S. Geol. Surv. Bull. 260* (1905), pp. 459–67; "Oil Fields of the Texas-Louisiana Gulf Coastal Plain," *U. S. Geol. Surv. Bull. 282*, 1906.

This theory is interesting because it is apparently the first appeal to the force of growing crystals to explain the uplift of the domes.

Veatch, in 1906, after describing the igneous intrusions of southern Arkansas, concluded with regard to the origin of the salt domes of northern Louisiana and eastern Texas as follows:

> Whether the forces producing these unique domes were in any way associated with those producing the intrusions just mentioned it is as yet impossible to say; but the irregularity of their distribution, the great symmetry of all the domes which have been carefully studied, the difficulty of explaining this symmetry by any manner of folding not associated with igneous intrusions, and the suggestion which this symmetry carries of force applied at one point from below, just as a sharp-pointed little dome might be formed in a sheet of dough by pushing upward with a blunt pencil, indicate similar igneous intrusions beneath these great thicknesses of relatively plastic, recently deposited cretaceous sediments as the cause of these domes.[1]

This conclusion, so similar to that previously put forward by Hager, was arrived at independently by Veatch, who had not yet become acquainted with Hager's theory.

Harris, in 1907, first announced his theory of dome uplift by the force exerted by growing salt crystals:

> The longer we study these peculiar structures the more convinced are we that although they may be located along lines of weakness, faults, or fractured anticlines, they are not to any great extent due to tangential, mountain-making forces, nor to volcanic upheavals, nor igneous plugs, as has recently been suggested, but to the slowly-acting, little understood, concretion-forming forces as well as the power of crystallization. Hot salines or calcareous solutions, coming from earlier Mesozoic or later Paleozoic beds beneath, rising perhaps by hydrostatic pressure alone, may very readily, upon reaching a level where the pressure is somewhat relieved and the temperature decreased, deposit some of their mineral contents.[2]

He notes, in support of his theory, that calcareous concretions seem to increase in size, bending adjacent shale beds upward or downward with irresistible force until the calcareous material within their reach is exhausted. As against theories of volcanic origin, he further notes that igneous plugs and dykes usually cause great irregularities in the earth's magnetic field, and that the area of the Winnfield sheet, which contains a number of domes, shows irregularities entirely too slight to indicate igneous activity in the region. In support of this contention, he later cited[1] the fact that the nearby volcanic rocks in Arkansas are magnetic.

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[1] A. C. Veatch, "Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas," *U. S. Geol. Surv. Prof. Paper 46* (1906), p. 29.

[2] G. D. Harris, "Notes on the Geology of the Winnfield Sheet," *Geol. Surv. of Louisiana*, *Report of 1907*, Bull. 5. Baton Rouge, 1907.

In his subsequent writing, Harris[2] restated and elaborated his theory which, in view of his careful and detailed presentation, the lack of a more plausible theory, and the position as an authority which his intimate knowledge of the American domes[3] gave him, received widespread and almost general acceptance. The most complete statements of this theory are to be found in the *Economic Geology* article and in *Bulletin No. 7* of the *Louisiana Report.* The theory is essentially as follows:

> Artesian waters, which had entered outcropping formations north of the general salt dome areas, having descended to great depths along pervious beds, becoming heated by the high earth temperatures existing at such depths, and taking into solution salts encountered in the Palaeozoic and Mesozoic formations, rose under hydrostatic pressure at points of weakness, occurring mainly at the crossing of faults in the pre-Tertiary formations. Deposition of salt by the cooling of this hot saline solution resulted in the formation of a slender pencil-like cone of rock salt. The forces exerted by the power of the growing crystals of salt, especially at the bottom of this salt cone, resulted in the cone being pushed continuously upward as long as deposition continued, the cone being beheaded by solution as it reached the zone of circulating underground fresh waters. Overlying sedimentary rocks were lifted and contiguous rocks tilted by the upthrust of the salt cone.

Harris evidently considered that the cap rock and associated minor minerals were deposited from other solutions after the salt solution had been cut off. He cites the work of Day and Becker[1] in support of his theory of crystal force. This paper states that the power of growing crystals (in general) may be assumed to be of the same order of magnitude as the crushing strength of the crystals themselves. Harris subjected a 4-inch cube of rock salt to a pressure of 50,000 pounds, without even cracking it, and concludes that growing salt crystals could "lift up 3,000, 4,000, and even 5,000 feet of such incoherent strata" as the Quaternary clays and sands.

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[1] "Magnetic Rocks," *Science*, N.S., Vol. 29 (1909), p. 384.

[2] G. D. Harris, "The Salt Domes of Louisiana and Texas," *ibid.* (1908), pp. 347–48; "Rock Salt," *Geol. Surv. of Louisiana, Report of 1907*, Bull. 7. Baton Rouge, 1908; "The Geological Occurrence of Rock Salt in Louisiana and East Texas," *Econ. Geol.*, Vol. 4 (1909), pp. 12–34; "Oil and Gas in Louisiana with a Brief Summary of Their Occurrence in Adjacent States," *U. S. Geol. Surv. Bull. 429*, 1910; "Immense Salt Concretions," *Popular Science Monthly*, Vol. 82 (1913), pp. 187–91.

[3] Harris' Bull. 7 of the *Louisiana Geological Survey Report* and Bull. 429 of the *United States Geological Survey* are still the most complete general descriptions of American salt domes available to the student, notwithstanding the fact that in the fifteen years since their publication our knowledge of these interesting structures has increased greatly.

Coste, in 1909, elaborated his former theory of volcanic origin, noting:

> In the Mexican oil fields the volcanic action has been a little more intense and instead of only the hot gases, vapors and waters piercing up more or less through the horizontal strata to form the salines, as in Texas and Louisiana, we see the volcanic lava cones themselves piercing up boldly through the plains. There is no doubt that these lava cores in Mexico surrounded with petroleum and other solfataric emanations are one and the same volcanic phenomenon as the vertical chimneys of salts, hot waters and hot petroleums of the Texas-Louisiana salines.[2]

Campbell,[3] in 1911, reviewed theories regarding the Texas domes. He concludes that the best hypothesis put forward regarding origin is that of Harris, but believes that Hager's volcanic hypothesis had derived considerable support from the discovery of oil in the vicinity of igneous plugs in Mexico.

Clapp,[4] in 1912, reviewed the salt-dome structures. He does not arrive at a definite conclusion as to origin, merely noting that the Harris theory is the one most commonly accepted and that Hager's theory "would seem to be supported by the existence of volcanic plugs in the Coastal Plain of Mexico accompanied by many of the Texas phenomena."

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[1] A. L. Day and G. F. Becker, "On the Linear Force of Growing Crystals," *Wash. Acad. Sci., Proc.*, Vol. 7 (1904), pp. 283–88.

[2] Eugene Coste, "Petroleum and Coals," *Jour. Can. Min. Inst.*, Vol. 12 (1909), p. 290.

[3] Marius R. Campbell, "Historical Review of Theories Advanced by American Geologists to Account for the Origin and Accumulation of Oil," *Econ. Geol.*, Vol. 6 (1911), pp. 363–95.

[4] G. F. Clapp, "The Occurrence of Oil and Gas Deposits Associated with Quaquaversal Structure," *ibid.*, Vol. 7 (1912), pp. 364–81.

Turrentine,[1] in 1913, after considering the Hill-Harris and Hager theories as possible, concludes that the formation of salt domes as the result of great pressure on plastic salt masses of the inclosing, less plastic rocks is a theory whose assumptions are less violent. He notes that the plasticity of salt masses is a known and not an assumed quantity, and considers:

> If at ordinary temperatures this quantity is insufficient to account for the fluidity which has been exhibited by the masses comprising the salt domes, it may be easily assumed that the salt was warmed to its melting-point by volcanic heat.

He further considers:

> The formation of salt domes, then, would be the result of ascending columns of fused sodium chloride. Recrystallization would occur when the surface had been approached, being induced by lower temperature or lower pressure, or both. Crystal formation, as suggested by Harris, may have added its forces to the pressure of the ascending molten mass.

Cowles,[2] in 1913, suggested osmotic pressure of diffusing fresh water above salt water under a hydrostatic head as a cause of "bursting upward" where resistance is least to form a salt dome.

Lucas,[3] in 1914, states that he "has long held the opinion that igneous rock in the form of laccoliths, batholiths, or sills may underlie the salt domes of Louisiana, Texas, and elsewhere." He further states that he has "held the opinion, with Mr. Coste, that emanations of gas through these domes constitutes evidences of volcanic origin," but that "the salt was not deposited by evaporation, but must have been deposited by saline waters ascending from great depths."

In another paper reaffirming his theory of volcanic origin of oil, Coste continues with regard to salt domes:

> That these are solfataric volcanic emanations is made plain by the occurrences of oil a little farther south, along the same coastal plain, in Mexico. There one can actually observe numerous volcanic necks of olivine basalt, scattered at

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[1] J. W. Turrentine, "The Occurrence of Potassium Salts in the Salines of the United States," *U. S. Dept. of Agriculture, Bureau of Soils, Bull. 94.* Washington, 1913.

[2] A. H. Cowles, *Min. & Met. Soc. Amer. Bull. 57*, Vol. 6 (1913), p. 44.

[3] A. F. Lucas, "Discussion of Hoefer's Paper on 'The Origin of Petroleum,'" *Trans. Amer. Inst. Min. Eng.*, Vol. 48 (1915), p. 494.

wide intervals, and also distributed along fault lines similar to the lines connecting the salines of Texas and Louisiana.[1]

Washburne,[2] in 1914, seems to favor the theory of volcanic origin, regarding the salt as having been precipitated from saturated brines of sedimentary origin by hydrochloric acid from igneous intrusions.

Siebenthal,[3] in 1915, after reviewing current theories of salt-dome origin, concludes in favor of deposition from solution from alkaline-saline, sulphureted waters of artesian origin and that "the very close similarity of the deposits and the artesian waters of the saline domes to those of the Joplin region indicates similarity of origin." His consideration of the domes is confined chiefly to Belle Isle, where Veatch[4] had noted the presence of fairly large masses of galena, sphalarite, pyrite, chalcopyrite, and barite in clay strata over the salt.

Norton,[5] in 1915, suggested still another somewhat complex variation of the volcanic and deposition from solution theories. He regarded the initiation of the domes as resulting from "the intrusion of molten rocks into the underlying Paleozoic sediments along lines of structural weakness." He postulated the building up of a pipe of calcareous sinter and gypsum from hot-spring deposits—contemporaneously and balanced with continued sinking of the coast and deposition of sediments, the dissolving of the lower part of this sinter pipe and deposition of salt from solution in the space formerly occupied by it, and the covering of the whole, in the case of the coastal domes, by 1,000 feet of later Tertiary sediments.

Dumble[6] regards this theory as one "which seems a step in advance of former ones," but Harris, in discussing the theory, points out the lack of evidence of volcanic activity, in fact, the evidence against such activity, and particularly the entire neglect of the theory to suggest any satisfactory explanation of the dome structure which is so marked a characteristic of this form of salt deposit.

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[1] E. Coste, "Rock Disturbances Theory of Petroleum Emanations vs. the Anticlinal or Structural Theory of Petroleum Accumulations," *ibid.*, p. 510.

[2] C. W. Washburne, "Chloride in Oil-Field Waters," *ibid.*, pp. 687–94.

[3] C. E. Siebenthal, "Origin of the Zinc and Lead Deposits of the Joplin Region," *U. S. Geol. Surv. Bull. 606* (1915), pp. 208–11.

[4] "The Five Islands, Louisiana," *op. cit.*

[5] E. G. Norton, "The Origin of the Louisiana and East Texas Salines," *Trans. Amer. Inst. Min. Eng.*, Vol. 48 (1916), pp. 502–11.

[6] E. T. Dumble, "The Occurrence of Petroleum in Eastern Mexico as Contrasted with Those in Texas and Louisiana," *ibid.*, Vol. 52 (1916), p. 263.

Lucas,[1] in 1917, after vaguely invoking volcanic origin, merely states: "As to the manner in which the salt with its gas and oil inclusions attained its present position, at a depth of 1,500 to 3,171 feet—whether in solution or as semi-plastic mass, has never been satisfactorily explained."

Kennedy,[2] the dean of American salt-dome students, in 1917 suggested that the salt masses were formed by precipitation of salt and calcareous minerals from thermal springs in small depressions or ponds along lines of weakness corresponding to the present dome alignment, on a gradually sinking coast, and that the source of the salt was Tertiary and younger rather than Paleozoic rocks. This theory differs but slightly from that of Norton and seems to be open to similar criticism.

Shaw,[3] in discussing the various possible origins, presents no conclusions, but notes that in his study of the mud lumps of the Mississippi Delta, the question arose of whether salt domes might not be due to isostatic forces, to some gravity-induced solid or semi-solid flowage.

Hopkins,[4] in 1917, expressed the view that the structural conditions found at salt domes are such as "are most commonly produced by igneous intrusion, of which no direct evidence has been found in any of the numerous salt domes of the Gulf Coast," and that it is quite probable that the forces forming the domes "were connected with igneous activity."

Deussen,[5] in 1918, stated that he was "inclined somewhat to the belief that the dome formation is originally initiated by volcanic action."

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[1] A. F. Lucas, "A Review of the Exploration at Belle Isle, Louisiana," *ibid.*, Vol. 57 (1918), pp. 1034–55.

[2] William Kennedy, "Coastal Salt Domes," *Southwestern Assoc. Pet. Geol. Bull.*, Vol. 1 (1917), pp. 34–59.

[3] E. W. Shaw, "Possibility of Using Gravity Anomalies in the Search for Salt-Dome Oil and Gas Pools," *Science*, N.S., Vol. 46 (1917), pp. 553–56.

[4] Oliver B. Hopkins, "The Palestine Salt Dome, Anderson County, Texas," *U. S. Geol. Surv. Bull. 661G* (1917), p. 264.

[5] Alexander Deussen, "Review of Development in the Gulf Coast Country in 1917," *Amer. Assoc. Pet. Geol. Bull.*, Vol. 2 (1918), p. 37.

Matteson,[1] in 1918, reviewed the principal theories of dome origin, stating objections to all of them, and concluding that the Harris theory "is one of the most ingenious that has been propounded, conforms with the field evidence, is plausible, and has been generally accepted by geologists familiar with the Gulf Coast region," and that "it forms an excellent, reliable working hypothesis in conducting field operations." This paper was more notable for the discussion which it aroused than for any original contribution to the subject. It provoked Lucas to reaffirm his adherence to the theories of Hager and Coste; G. Sherburne Rogers attacked the deposition from solution theories on grounds of quantitative sufficiency and guardedly advanced the theory of salt intrusion; Shaw objected to the theory of isostatic flowage on the grounds that the coastal plain sediments were lighter than salt. Coste restated his volcanic theory as follows: "I not only believe in the volcanic rocks under these domes but believe that the salt, the sulphur, and the hydrocarbon emanations are also absolute, direct emanations from below." Kirby Thomas advanced a variation of the deposition from solution theory. Washburne supported Roger's objections to the Harris theories and preference for the theory of salt intrusion. Anson G. Betts proposed a very improbable theory postulating the dissection of a salt bed by erosion, the burial of the buttelike outliers by sediments and the subsequent settling of the sediments. Kennedy defended the deposition from solution theories against Rogers' attack and suggested the Tertiary and Cretaceous as a source of the salt, rather than the Permian, objecting that the Permian was probably not present under the salt-dome region.

In this discussion, Rogers noted "the discovery, during the past summer, of volcanic ash in the sediment around one or two of the domes, of a rock resembling a porphyry in a well at Damon Mound; and of an undoubted igneous plug about fifty miles north of the salt-dome belt." Unfortunately, in the untimely death of Rogers we lost one our most interested and advancing students of this problem. It was impossible to get definite information on these reported occurrences of igneous rock. In his subsequent paper on intrusive origin, Rogers repeats his note on volcanic ash and on the igneous plug, but makes no further reference to the "rock resembling porphyry in a well at Damon Mound." The occurrence of volcanic ash is of no particular significance, and Pratt,[1] after an investigation of this report, concludes that the "igneous plug" is porcelanite from Grimes or Brazos County; that the "porphyry" is sedimentary rock fused by the frictional heat of core drilling, and that "it is likewise probably true that no rock of igneous character other than fused core-barrel samples has been obtained from Gulf Coast wells." This is doubtless the explanation of these references, but it is odd that Rogers, who had studied and published on porcelanite in the northwest, where it is of such common occurrence, should have mistaken these Texas outcrops.

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[1] W. G. Matteson, "Principles and Problems of Oil Prospecting in the Gulf Coast Country," *A.I.M.E.*, Vol. 59 (1918), pp. 435–91.

THIRD PERIOD (1916–25); STRUCTURAL OR SALT-FLOWAGE THEORIES

The theory of formation of American salt domes through the flowage of salt under pressure, and adaptation, so to speak, of the most generally accepted European theory of salt-structure origin, was foreshadowed by Lucas[2] in his statement that the salt of Jefferson Island seems to have been folded and contorted while still in a plastic condition; by Turrentine's conclusions regarding origin; by Shaw[3] in his query as to whether salt domes might not be due to isostatic forces, to some gravity-induced solid or semi-solid flowage; by Hahn's[4] description of European deposits; and by the experimental work of Adams[5] and Johnston and Adams[6] on the flowage of salt under pressure.

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[1] Wallace E. Pratt, "A Note on the Supposed Evidence of the Volcanic Origin of Gulf Coast Salt Domes," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5 (1921) pp. 91–94.

[2] *Op. cit.* [3] *Op. cit.*

[4] F. F. Hahn, "The Form of Salt Deposits," *Econ. Geol.*, Vol. 7 (1912), pp. 120–35.

[5] Frank D. Adams, "An Experimental Investigation into the Action of Differential Pressure on Certain Minerals and Rocks, Employing the Process Suggested by Professor Kick," *Jour. Geol.*, Vol. 18 (1910), p. 489.

[6] John Johnston and L. N. Adams, "On the Effect of High Pressures on the Physical and Chemical Behavior of Solids," *Amer. Jour. Sci.*, Vol. 35 (4th series, 1913), p. 251.

The theory was put forward seriously for American domes in 1917–18 by Van der Gracht, the writer, Dumble, and G. Sherburne Rogers, and has been most favorably received.

Van der Gracht, one of the first of European geologists to become intimately acquainted with our salt-dome problems, after discussing the German and Roumanian salt structures and their similarity with those of the Gulf Coast, concluded:

> I consider these saline plugs as having been *pushed upwards* by orogenic pressure, and not by recrystallization forces inherent in the rock salt. It is my firm belief that the intense lateral pressure has caused the rock salt to behave as a plastic mass and has squeezed it upwards not unlike a volcanic neck, wherever the overlying strata afforded a weak spot inviting passage.[1]

He regarded recrystallization as taking place but as an effect and not as a cause.

The writer, in 1918, reviewed the theory of volcanic origin with special reference to the suggested analogy with the oil fields of the Tampico-Tuxpam region, and concluded:

> The lack of evidence of any considerable volcanic activity in the salt-dome regions of Texas and Louisiana or in the salt-dome region of the Isthmus of Tehuantepec, Mexico, as well as the entire absence of any salt masses of the nucleus type in the Tampico-Tuxpam region, Mexico, a region of considerable volcanic activity, would seem to argue most strongly against the acceptance of the volcanic theory of salt dome origin. . . . .
>
> Finally, since the attractiveness of the theory of volcanic origin of salt dome lies in the similarity of structural effect produced by the intrusion of the salt in many domes to that produced by the intrusion of the igneous rock of a volcanic neck or plug, it follows that we are interested in the conditions and forces which caused the salt to act in a manner so like to that of an igneous magma. . . . .
>
> Rather, the structure of the domes would seem to make it evident that the salt itself must have flowed. Such flowage was most likely due to great pressure exerted upon buried salt masses by the weight of overlying rocks, and at considerable temperatures and probably accompanied, as has been suggested by van der Gracht, by recrystallization of the salt.[2]

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[1] W. A. I. M. von Waterschoot Van der Gracht, "The Saline Domes of Northwestern Europe," *Southwestern Assoc. Pet. Geol.* Vol. 1 (1917), pp. 85–92.

[2] E. DeGolyer, "The Theory of Volcanic Origin of Salt Domes," *A.I.M.E.*, Vol. 61 (1919), pp. 456–77.

In the discussion of this paper, J. A. Udden stated that neither this theory nor the volcanic theory explained the cap rock and held that, whatever theory might be developed, the Hill-Harris theory, which he evidently regarded as satisfactorily explaining the cap rock, was not likely to be entirely replaced.

Dumble, in his discussion of the same paper, gave an extended description of the domes, and put forward a theory which is essentially an intrusion theory but also, by definition, a volcanic theory and one which seems to the writer very interesting and one of the most plausible theories propôsed to meet our own special problem. His conclusions are as follows:

> The character and structure of the domes show conclusively that they are the result of orogenic action and that this activity has been manifested at different times and in different degrees.
>
> The interior domes and the Sabine Peninsula were begun by crustal movements at the end of the Upper Cretaceous, and were involved in later movements at the end of the Lower Eocene and during the Claiborne or Middle Eocene, resulting in total elevations of 2,500 feet [762 m.] or more above their normal horizon.
>
> Similarly, the coastal domes were elevated by orogenic forces acting after the deposition of the Lafayette and prior to that of the Port Hudson clays. The elevations in this case are fully as great as in those of the interior domes, as is proved by drilling. In the case of Damon Mound, the elevation does not appear to have entirely ceased, since the San Bernard River, flowing on its western side, seems to be still cutting its canyon where it crosses it, although to the north and south its banks are low and flat. The movements are most probably the result of isostasy.
>
> According to the writer's point of view, the question of vulcanicity cannot enter into the origin of the materials of which the domes are composed, since, although salt may be formed by volcanic emanations, we have here no need to invoke such a theory of its origin, since a more natural one is probable. Neither is it believed to be the actual dome producer, but rather an accompanying factor or feature of the forces which caused them.
>
> Both salt and anhydrite become liquid at far lower temperatures than any lava, and existing in considerable bodies, as they probably did here, could be readily forced into any opening caused by flexures or faulting of the crust above them more easily than a plug of basalt. Apparently this is what has occurred, and since the term vulcanism is used by Chamberlin and Salisbury "to embrace not only volcanic phenomena in the narrower sense, but all outward forcing of molten material, whether strictly extrusive or merely ascensive," it is thought to

cover the phenomena of the intrusive salt, gypsum, and anhydrite stocks in these domes, as fully as if the stocks were basalt or other rock material.

Rogers,[1] shortly afterward, published an exposition of the European theory and suggested the application of the theory of dome formation through salt flowage to the American domes. He described the development of the theory in Europe, the general outlines of the nature of European salt structures, and the plasticity of salt, and concluded: "The writer is inclined to believe that the Gulf Coast salt domes, like those in northwestern Europe and Roumania, are offshoots of bedded salt deposits, formed and forced upward by pressure in a semi-plastic condition." He argues Permian deposits of bedded salt as the most likely source of the salt and pressure by lateral thrusting of deeply buried rocks as the most plausible source of pressure, pressure occasioned by igneous intrusion (batholithic) as possible, and by isostatic adjustment as improbable. He argues that cap rock may have been formed by precipitation from solution by ground waters, and that we are hardly justified as yet in accepting the German view of regarding the cap rock as a residue left from the dissolving of the salt dome. Rogers also quotes Mrazec, notable for his studies of Roumanian salt structures and who had recently visited the Gulf Coast region, as agreeing to the intrusive origin of the domes. He quotes Becker, upon whose work on the force exerted by growing crystals Harris bases his theory of dome uplift through the power of crystallization, as follows:

> I do not for a moment believe that the linear force of growing crystals has caused intrusion of salt plugs or doming of the sediments. It may to some extent have modified the action on the walls and have aided in causing distortions within the mass. Recrystallization of the salt *in situ* would obliterate the strains in such crystals.

In a discussion of this paper, the writer[2] argued for the formation of the cap rock by deposition from solution after the salt mass had been formed and, citing Cameron's experiments upon the solubility of gypsum in saline solutions, suggested that the salt might have been the agent which precipitated gypsum or anhydrite from solution.

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[1] G. Sherburne Rogers, "Intrusive Origin of the Gulf Coast Salt Domes," *Econ. Geol.*, Vol. 13 (1918), pp. 447–85.

[2] E. DeGolyer, "Origin of the Cap Rock of the Gulf Coast Salt Domes," *ibid.*, pp. 616–20.

Lucas,[1] in 1918, again advocated the volcanic origin of the salt domes and, by the publication of a hypothetical section, rather cleared up his previously expressed ideas. His section shows the salt dome above a laccolith and separated from it by arched beds of Cretaceous and younger rocks.

The writer,[2] in 1919, suggested that the formation of the interior group of salt domes was of comparatively recent date and might not yet be complete. He questioned whether a salt dome whose formation can be established beyond doubt as having occurred in pre-Tertiary time can be cited, and suggests that theories of origin implying long life or great age for a dome should be looked upon with suspicion.

Powers,[3] in 1920, regarded the tectonic theory of dome origin as acceptable, granted the existence of a source bed of salt.

Lucas, in 1920, presented his last statement as follows:

> According to my present views, the salt domes occur on lines of structural weakness that are responsible for the location of the plugs of salt, whether the latter originated from solutions, as I have been inclined to believe, or are products of extrusion from the deeply buried older formations, whose thrusting or faulting is responsible for the "pre-existing weakness" already mentioned. . . . .
>
> Further movement along the line of weakness may well have occurred subsequent to the original dislocation and possible saline extrusion, and it is along fractures thus produced in the salt plugs that the sulphur and other caprock materials have been brought to the surface.[4]

White,[5] in 1920, referred to the "pressure theory of the origin of the salt plugs" as one "which seems to demand acceptance."

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[1] Anthony F. Lucas, "Possible Existence of Deep-seated Oil Deposits on Gulf Coast," *A.I.M.E.*, Vol. 61 (1919), pp. 501–19.

[2] E. DeGolyer, "The West Point, Texas, Salt Dome, Freestone County," *Jour. Geol.*, Vol. 27 (1919), pp. 647–63.

[3] Sidney Powers, "The Butler Salt Dome, Freestone County, Texas," *Amer. Jour. Sci.*, Vol. 49 (1920), pp. 127–42.

[4] A. F. Lucas, "Urgency for Deeper Drilling on the Gulf Coast," *Trans. Amer. Inst. Min. & Met. Eng. Preprint No. 1004*, 1920.

[5] David White, "Genetic Problems Affecting Search for New Oil Regions," *ibid.*, Vol. 65 (1920), pp. 176–98.

Mills and Wells[1] in 1919, advanced the theory that among the possible causes of deposition of salt-dome materials from solution is the evaporation of water from solution by expanding gases. Accepting the intrusion theory of dome origin as possible, they advance the effect of evaporation as having played a large part in the formation of the domes, but do not claim that the theory fully explains their formation.

Washburne,[2] in 1920, attacked the Mills and Wells hypothesis of precipitation from solution by evaporation as an explanation of origin. The argument against this theory specifically was largely on the grounds of quantitative insufficiency. Deposition from solution theories generally were held improbable, because of dilution of the hypothetical rising salt solution by meteoric waters, particularly artesian waters, and consequently salt would not be deposited. Washburne regards the theory of intrusive origin as more acceptable. He pointed out limitations of the writer's suggestion of cap-rock deposition from solution by increased salinity.

Matteson,[3] in 1921, attacked the theory of intrusive origin as set forth by Rogers and proposed a theory of "secondary intrusion" which postulated the deposition of salt masses and limestone from solution, largely through gas evaporation of the water; initial movement and uplift through the force of crystallization, and increase in volume by the conversion of limestone into gypsum; and secondary intrusion by salt flowage resulting from lateral thrust and compression. This theory seems to be a merger of most previously expressed theories and in sum total inherited more of their weakness than of their strength. Nor was its author happier in his attempt to discredit the very actual analogies between European and American salt structures by a catalogue of their differences and neglect of their similarity.[4]

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[1] R. van A. Mills and R. C. Wells, "Evaporation and Concentration of Waters Associated with Petroleum and Natural Gas," *U. S. Geol. Surv. Bull. 693*, 1919.

[2] C. W. Washburne, "Oil-Field Brines," *Trans. Amer. Inst. Min. & Met. Eng.*, Vol. 65 (1921), pp. 269–94.

[3] W. G. Matteson, "Secondary Intrusive Origin of Gulf Coastal Plain Salt Domes," *ibid.*, pp. 295–334.

[4] No one can read the Washburne and Matteson papers and their discussions without delight at the various solemn warnings against the sins of speculation in dealing

Barton,[1] in 1921, gave favorable consideration to the theory of intrusive origin of the salt at West Columbia, explaining in considerable detail the probable similarities and differences between the intrusion of a salt plug and of a volcanic neck. He rejected, for American domes, the European theory that cap rock is a residual deposit resultant upon the solution of an impure salt mass on the grounds that the salt of the American domes is extremely pure and that the cap rock does not always cling closely to the surface of the salt mass as would residual material.

Cheney,[2] in 1922, advanced a theory that the Texas interior domes, except Grand Saline, occur on the crest of an anticlinal fold parallel to the Balcones fault and Mexia anticline. He regarded the salt as of Middle or Lower Cretaceous age, the domes to have been formed by cross-folding and erosion in pre-Tertiary time, and the apparent vertical thickness of the salt is ascribed to close folding, and dome structure in the younger formations to continued folding. This theory was discussed by Heald,[3] who regards it as "based entirely upon assumptions, none of which can at present be verified, and some of which seriously tax the imagination and credulity," and disposes of it in some detail.

In 1923, Powers and Hopkins[4] concluded that "the deposition of salt from solution in fissures or other openings seems to be a self-limited and inadequate process to account for the domes" and in the lack of information that would suggest any other explanation "pre-

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with this subject of dome origin. The truth is that whoever touches this enticing subject within the present century, and perhaps for longer, is bound to indulge freely in speculation. The problem is so broad, the factors involved are so numerous, and the work to be done with regard to salt structures is so great that we cannot for many years to come expect to hedge our tendencies to speculate to any very narrow range by the limits of exact knowledge.

[1] D. C. Barton, "The West Columbia Oil Field, Texas," *Amer. Assoc. Pet. Geol. Bull.*, Vol. 5 (1921), pp. 212–51.

[2] Charles A. Cheney, "Salt Domes of Northeastern Texas," *Oil and Gas Jour.*, Vol. 20 (Jan. 6, 1922), No. 32, pp. 82–83.

[3] K. C. Heald, "Salt Domes of Northeastern Texas. A Review," *Amer. Assoc. Pet. Geol. Bull.*, Vol. 6 (1922), pp. 58–59.

[4] Sidney Powers and Oliver B. Hopkins, "The Brooks, Steen, and Grand Salt Domes, Smith and Van Zandt Counties, Texas," *U. S. Geol. Surv. Bull. 763* (1923), pp. 179–239.

sented the tectonic theory as best explaining the origin of the domes of Louisiana and Texas."

White, in a very recent paper, in considering the gravity anomalies observed at Damon Mound, states:

> Admitting that the salt is extruded, it would hardly be forced to overcome so great resistance except by powerful lateral thrusts, first forming an anticline, and later presumably overturning the fold before producing the fracture or tearing of the deeper consolidated strata through which the salt might press upward on lines of least resistance. Faulting or overturned buckling beneath the plug is a normal geologic probability. The movement squeezing the salt upward across thousands of feet of strata is possibly post-Miocene.[1]

Deussen,[2] in 1924, published the results of work done some years previously in southwestern Texas. He describes several salt domes but reaches no very definite conclusion regarding origin. He states, "Salt domes represent intrusions of massive saline cores into sedimentary formations," and notes that there are three main theories of origin: the volcanic, deposition from solution, and salt-flowage theories. He regards the theory of precipitation from ascending solution as "more likely" than the theory of volcanic origin.

DISCUSSION OF TYPES OF THEORIES

The problem of developing an acceptable theory to explain the origin of the salt domes of North America—of the Texas and Louisiana province—is essentially one of trying to explain, in the simplest manner possible, the formation of these peculiar structures by known and adequate geologic processes. The theory which best meets this requirement is more rational and less speculative than one which does not, and as such is entitled to at least a tentative general acceptance. The most complicated theory yet put forward, and this is saying a great deal, may be the correct one, but probabilities are strongly against it and we are here dealing with probabilities rather than possibilities.

The solution of the problem has not been possible in the past in the insufficient state of our knowledge. The probable alternative hypotheses for methods of salt-dome origin have been well outlined by previous students of the problem.

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[1] David White, "Gravity Observations from the Standpoint of the Local Geology," *Geol. Soc. Amer. Bull.*, Vol. 35 (1924), pp. 207–77.

[2] Alexander Deussen, "Geology of the Coastal Plain of Texas West of Brazos River." *U. S. Geol. Surv., Prof. Paper 126.* Washington, 1924.

The writer has no new theory to propose. The weight of the evidence which has been accumulating with increasing rapidity during the past very few years has been, however, cumulatively in favor of the sedimentary salt-flowage theory, and now with the recent discovery at Markham the writer believes that this theory has been established with a high degree of scientific probability.

The theories of dome origin already put forward fall into four general groups: (1) those regarding the domes as old outliers; (2) those regarding the salt-dome materials—the salt core and cap rock—as having been precipitated from solution; (3) those regarding the domes as of volcanic origin; and (4) those regarding the salt as a plastic or semiplastic body forced by pressure into its present position. All of the theories which seem to be worthy of serious consideration belong to one of these groups or, with variations and combinations, to two or more of them.

1. The first group of theories—those which regard the domes as old Cretaceous outliers in Tertiary seas—belong to the earliest stages of our study of salt domes. They received general acceptance in their time, but were discarded when we began to know something of dome structure, and they now no longer demand serious consideration.

2. The deposition from solution theories, first advanced by Goessmann, and in greater detail by Hill and Harris, are not acceptable in their simpler forms, since they offer no adequate explanation of the uplift of the strata overlying and contiguous to the salt. An attempt is made to remedy this deficiency by an appeal to the force supposed to be exerted by growing crystals—a modification of the theory which was suggested by Fenneman and elaborated by Harris. This modified theory has received favorable consideration and widespread acceptance, but is not acceptable to the writer. He does not believe that such immense bodies of salt—stocks averaging a mile in diameter and thousands of feet in thickness—were ever deposited from solution, nor does he believe that the ingenious appeal to force exerted by growing crystals can satisfactorily explain the tremendous forces which evidently operated in the formation of the dome.

Brines are of the commonest and most widespread occurrence, yet comparatively pure salt deposits which can be proved definitely to have been deposited from solution, except in bedded deposits, are rare indeed, and quantitatively of distinctly minor importance. Nor can it yet be established that the force exerted by crystals growing from aqueous solution, as proposed by Harris, has ever operated on a scale adequate to explain force of the magnitude operative in the formation of salt domes. Harris cites the compression of shales enveloping a calcareous concretion as evidence of the actual operation of this force as a geologic process, but as negative evidence we have any number of mineral deposits, known to have been deposited from solution and of minerals which should exert even greater forces in crystal growth than most salt, where there is lack of evidence of force of crystal growth of anything like the magnitude necessary to explain salt-dome formation. It is worthy of note that Becker, the geophysicist upon whose experimental work on the force exerted by growing crystals the Harris theory largely rests, concludes: "I do not for a moment believe that the linear force of growing crystals has caused intrusion of salt plugs or doming of the sediments." Furthermore, the mechanics of the Harris theory is weak. The formation of a salt mass of dome magnitude would have had to be a slow and relatively continuous process in order to provide enough brine to supply the salt. The writer cannot conceive of free brine circulation—the arrival of fresh brine and escape of the lean solution—in a cavity, where the salt already deposited is exerting a pressure great enough to lift thousands of feet of strata. The process would seem to be self-inhibiting long before a salt dome could have been formed. The only variations of the theory of deposition from solution which overcome this difficulty, those of Norton and Kennedy, do not explain the dome uplift.

3. The theories of volcanic origin, first proposed as a pure speculation by Thomassey and more seriously by Lee Hager and Veatch, are worthy of serious consideration, if for no other reason, because they have appealed so generally to the men most intimately acquainted with the North American salt domes. Lee Hager, Lucas, Deussen, Clapp, Veatch, Dumble, Oliver B. Hopkins, and Washburne have at one time or another expressed themselves as favorably

inclined toward a theory of volcanic origin. The writer believes that this general appeal results from the fact that structurally an igneous plug is the only geological feature known to us which even remotely resembles a salt dome, and the similarity of the two is indeed striking. He believes, however, since the salt in the one occupies the same structural position and evidently performed the same uplifting function as the igneous magma in the other, that if the problem had been more clearly thought out, we would have concerned ourselves with the conditions and forces which caused the salt to act in a manner so like to that of an igneous magma instead of appealing to volcanic origin to explain salt domes.

All theories of volcanic origin are open to the objection that there is no positive evidence of volcanic activity in the salt-dome regions of North America, an objection well recognized by proponents of the theory. The comparatively high temperatures of the oil and waters associated with the domes, as well as the high sulphur content of the oils, may be interpreted as evidence of vulcanism, but they are susceptible of other explanations and are not at all conclusive. The occurrence of oil in association with volcanic rocks in the Tampico-Tuxpam region of Mexico has been cited many times in support of this theory, but the Mexican occurrence is some hundreds of miles removed from the salt-dome region of Mexico and has no definite bearing on the matter in any way.

All of the theories of volcanic origin are open to the further very definite objection that no important salt deposits ascribable to volcanic origin are known elsewhere in the world. Surely, if salt deposits of dome magnitude are the result of volcanic action, we should find at least an occasional important salt deposit in regions of known volcanic activity which could be proved to be of volcanic origin.

The volcanic theories which suppose that the salt of the domes was deposited from solution, such as Hager's theory or, more vaguely, from "emanations," such as the theories of Coste and Lucas, are open to the same objections as the other deposition from solution theories.

Dumble's theory is a tectonic theory rather than a volcanic theory, though he evidently appeals to conditions similar to those supposed to give rise to lava pockets[1] to bring about the plastic or liquid conditions of deeply buried salt and anhydrite and thus promote its free flowage, and he refers to this process as included within Chamberlin and Salisbury's definition of volcanic phenomena.

4. The tectonic, structural, intrusion, or salt-flowage theories of salt-structure formation were first developed by European geologists to explain the origin of the salt structures of Germany and Roumania. Its application to the American problem was suggested by Hahn and Turrentine and was seriously put forward by Van der Gracht, the writer, Dumble, and G. Sherburne Rogers.

All of these theories postulate a deeply buried bed of salt of sedimentary origin and flowage in a semiplastic state, under pressure induced by orogenetic movements, or the weight of superincumbent strata to its present position. This, briefly, is the intrusive-origin theory. The writer believes it to be the most acceptable and most rational of the theories put forward to explain the origin of salt domes. It has the very definite and, to the writer's mind, conclusive superiority over all other theories of being equally suitable as applied to salt structures in general. Granting, for the sake of argument, the claims of their proponents to the validity of theories of deposition from solution or volcanic origin, or their various combinations, as satisfactory explanations of the origin of American salt domes, they lose nine-tenths of their attractiveness if they do not break down entirely, when an attempt is made to apply them to other forms of salt structures such as the long anticlinal ridges of Germany and Mexico. This objection, to the writer's mind, is decisive, since the genetic kinship of all forms of salt structures, including salt domes, is obvious. Furthermore, the tectonic theory seems to have been established for German salt structures, where the age and source beds of the salt are known, beyond reasonable doubt.

ORIGIN OF THE NORTH AMERICAN DOMES

The writer firmly believes that the North American salt domes, i.e., the salt structures of the Texas-Louisiana province, are plugs of salt intruded into previously almost undisturbed Tertiary and Cretaceous formations from deeply buried salt structures; that these deeply buried salt structures were formed by orogenetic forces; and that the flowage of the salt in a plastic or semiplastic state from original bedded deposits was induced by compression resulting from folding.

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[1] See the chapter on "The Origin of Pockets of Molten Rock" in W. H. Hobbs's *Earth Evolution and Its Facial Expressions.* New York, 1921.

That the salt plugs are intruded into their present position by salt flowage under pressure from below, the writer considers to be reasonably established. Salt has been shown to be plastic or semiplastic and to flow under pressure. Highly folded, or semiflow structure has been found in the salt core of every salt structure where opportunity exists for its adequate examination, so far as is known. This is true for the German, Roumanian, and Mexican salt structures and for the Cardona, Spain, salt structure, and it is true for the American salt domes. Aside from the general relationship and arrangement of the salt-dome materials and contiguous rocks, this flow structure in the salt is the most common characteristic of salt structures. The upturned contiguous sedimentary rocks, dipping away from the salt in all directions, is further evidence that the salt core is intrusive, but most striking of all is the great uplift of the rocks overlying the salt-dome material. The Woodbine sands outcrop at the surface of the Palestine, Texas, salt dome where, except for the structural disturbance arising from the formation of the dome, one would expect to find Mount Selman beds—indicating an uplift of 3,200–4,200 feet. Jurassic limestones are found at the surface of the Tonolapa structure, near Chinemeca, Vera Cruz, where, except for the structure, one would expect to find beds of Miocene or younger age, indicating an undetermined uplift, for the section is not well known, but probably of the magnitude of 10,000 feet as a minimum. Van der Gracht cites Heligoland, which he regards as a salt structure, as indicating an uplift of some 20,000 feet. Uplifts of this magnitude in very sharp and narrowly defined domes, especially in areas of otherwise little or no structural disturbances, are almost impossible to explain except as the result of salt intrusion from below.

The writer considers that the salt domes of the coastal and interior groups are of contemporaneous origin. He holds this view in the absence of contrary evidence, and because it seems quite improbable that two independent groups of so unusual type of phenomena as salt domes should have been formed independently so near to each other in a single geologic and geographic province such as the Cretaceous-Tertiary overlap of the Gulf Coastal plain.

Dumble has suggested a different geologic history for the domes of the interior group from those of the coastal group, and Deussen, Powers, O. B. Hopkins, Dumble, and other salt-dome students conclude for intermittent growth of the domes, their argument being based on evidence of apparent lacunae in the geologic section observed at the surface of certain of the Texas interior domes, notably Deussen's statement that the Midway is absent in the Palestine dome. The writer has never accepted this theory, holding rather that the Midway might yet be found at Palestine or that, if missing, its absence in so sharp, steeply folded, and faulted a structure could easily be due to mechanical suppression such as is of common occurrence in Roumanian and other salt structures. More recent work has resulted in the finding of Midway exposure at Keechi and Palestine.[1] This new evidence would seem to eliminate such bases as existed for the arguments cited in favor of separate histories for the two groups.

As to the mechanical progress upward of the salt core, the writer is inclined to believe that it would have been somewhat intermittent. Given a salt body acting as an extremely viscous liquid and a more or less constant pressure, upward progress of the salt core, assisted doubtless by tidal kneading and water lubrication, would be regular and gradual only so long as the material penetration was homogeneous. It can be conceived that if the salt core should encounter a sufficiently resistant bed, progress of the core would be halted until pressure enough had accumulated to enable it to break through and continue its upward growth. There is also some evidence in domes of the New Iberia, Louisiana, type, that younger and smaller salt cores may have sprung from older domes which had already reached a state of equilibrium.

This tectonic theory postulates the existence of a series of sedimentary rocks containing considerable deposits of bedded salt which must be older than the oldest rocks known to be involved in the formation of any of the domes; that is to say, Lower Cretaceous or older. It presupposes, as well, the folding of this series of rocks to a degree intense enough to form salt structures before the deposition of the oldest rocks involved in the known domes—probably before the Upper Cretaceous.

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[1] Private communication from Donald C. Barton based on examination made by Barton and F. B. Plummer and paleontologic determinations by Israelsky.

The weakness of this theory heretofore has been that we have had no knowledge of the existence of such bedded deposits of salt. The existence of the salt masses themselves is, to the writer's mind, definite evidence of the existence of such older deposits of bedded salt, but he grants that this evidence would hardly be admitted by one not already strongly convinced of the intrusive nature of the salt plugs. The recent discovery of salts containing fossil algae and potash salts in the core of the Markham salt dome, however, and the discovery of potash salts in the Mexican salt structures seem to establish the sedimentary origin of the salt beyond reasonable doubt. It may be that further examination of the algae salts will give some clue as to age. Dumble argues bedded deposits of Lower Cretaceous age as the source of the dome salt, and the finding of anhydrite and red beds in the Lower Cretaceous of northwestern Louisiana and north Texas, as well as the reputed occurrence of salt itself in the Lower Cretaceous near Ojinaga, Chihuahua, give great support to his argument. In arguing for a Lower Cretaceous source of salt he is supported by so eminent an authority as Professor Schuchert, who says:[1] "The best place to get your salt is from the Comanchean."

On the other hand, there is little evidence, in outcrop around the perimeter of the Gulf Coastal plain, that the Lower Cretaceous has suffered structural disturbances such as are postulated by this theory, or sufficient to result in the formation of salt structures. The writer would be inclined to consider the age of the salt source beds as pre-Cretaceous, but here we are in quite as great difficulties. The existence of Jurassic or Triassic rocks is entirely conjectural, and Professor Schuchert opposes the existence of any Paleozoic strata which might serve as a source of the salt, it being his opinion that the Cretaceous of the Gulf Coastal plain is underlaid directly by pre-Paleozoic metamorphics.

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[1] Personal letter to the writer.

If one considers the structure of the Paleozoic rocks around the perimeter of the Cretaceous-Tertiary overlap of the Gulf Coastal plain as a tectonic frame of reference, he is struck immediately by the conformability of the well-determined, northeast-southwest alignment of the salt domes of the coastal group to the general trend of pre-Cretaceous Appalachian structure, and the almost equally marked northwest-southeast alignment, as shown in the Five Islands, to the general structural trend of the pre-Cretaceous, Arbuckle-Wichita structure. The alignment of the Texas interior domes, on the other hand, follows more nearly the trend of the Balcones fault system. This argument, vague and indefinite as it is, does not favor the theory of Cretaceous salt, but it is not definite in support of pre-Cretaceous salt structures.

We have learned much regarding structure in the Cretaceous rocks of the Gulf Coastal plain as a result of the development of the Powell, Mexia, and Luling oil fields, and the subsequent geological explorations to which they gave impetus, and it may be that at some future date we shall possess sufficient knowledge to serve as a basis for a more definite conclusion as to the source of the salt of the domes. The argument at present favors the Lower Cretaceous, though the author cannot escape the feeling that although present knowledge may support Professor Schuchert's conclusion against the existence of pre-Cretaceous sedimentary rocks, further investigations may bring about a different opinion.

The cap-rock problem, to the writer's mind, is separate and distinct from the problem of the origin of the salt core of the dome. The occurrence of salt domes without cap rock would seem to indicate the truth of this assumption.

The common occurrence of cap rock in salt domes, and even salt structures, however, makes a consideration of origin desirable to round out any acceptable theory of salt-dome origin.

Whether one accepts the theory of tectonic origin of the salt domes or not, after giving due consideration to the position of the cap rock, overlying the flat top of the salt, but in the American domes at least seldom extending down its sides, there would seem to be but three possible methods of cap-rock formation: (1) as a residuum of rocks or minerals, originally interbedded with the salt or disseminated within it, left from the solution of the salt by circulating waters; (2) as a deposit from solution; or (3) as a formation encountered by the salt core during its intrusion from below and brought up with it.

The writer is inclined to regard the theory of residual origin, developed by European geologists to explain the cap rock of their salt structures, as the most acceptable theory to account for the cap rock of American salt domes. During the intrusion of the salt core, according to the adaptation of this theory to our particular problem, the upper end of the salt plug would have been dissolved away by circulating fresh waters as successive water-bearing strata were encountered, thus forming the flat top so characteristic of our salt plugs, and leaving a residue consisting chiefly of anhydrite, which was subsequently altered to the cap rock found at present. This theory presents no particular difficulties in Germany, the place of its origin, since considerable quantities of anhydrite are known to be interbedded in the German salt masses. The weakness of the theory as applied to American domes is that there is but little evidence of considerable quantities of anhydrite in the salt core. For the most part, salt cores from American domes show so little anhydrite that it might require the dissolving of 100 feet or more of salt core to leave a residue of 1 foot of cap rock. Occasional samples, however, show considerable amounts of anhydrite.

Chapman[1] notes that rock salt encountered in the Hockley dome shows "some anhydrite in the upper parts of the deposit."

Barton notes that the core from 2,110 feet, Fitzsimmons No. 1, Brenham salt dome, is described as "40 per cent salt—60 per cent anhydrite." He examined a core from 2,172 feet in the same well and describes it as "50 per cent salt, 50 per cent saccharoidal anhydrite, interbedded in parallel zones about 1 centimeter thick." He further describes these zones as indistinctly bounded and grading into one another. The center of the salt bands was pure, clear, and transparent salt, and that of the anhydrite zones seemed to be pure, medium-grain saccharoidal anhydrite of the characteristic salt-dome cap type.

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[1] Lewis C. Chapman, "The Hockley Salt Dome," *Bull. Amer. Assoc. Pet. Geol.*, Vol. 7 (1923), pp. 297–99.

Interbedded salt and anhydrite are also of common occurrence in the Mexican salt structures, but here the anhydrite not only occurs far down on the flanks, as in the German structures, but is also interbedded with shale as well. The Mexican occurrences are of a type much more complex than elsewhere, so far as is known to the writer. It seems probable that in a salt structure such as Ixhuatlan, much of the anhydrite encountered in drilling is part of the salt core and is in no sense cap rock as we are accustomed to use the term in the United States. Much original anhydrite of this type is found in the salt cores of the German structures. True cap rock is also found in both the German and Mexican structures.

Recent drilling at Markham has also resulted in the finding of interbedded salt, shales, and anhydrite in a position far down on the flanks of the dome. The position of these materials suggests that they also may belong to the original salt core.

The limestone of the cap rock may be material encountered by the salt dome in its upward progress—plucked material, so to speak—but the writer is inclined to regard it and the gypsum as alteration products of anhydrite and to regard the sulphur, oil, and other minor minerals as secondary accumulations, deposits from circulating waters, and alteration products.

CONCLUSIONS

In presenting his conclusions, the writer cannot well brief the present paper, but prefers to give his own working hypothesis as to the origin of the salt domes of North America, i.e., the salt structures of Texas and Louisiana.

The salt and anhydrite of the salt core are believed to have been deposited originally in lagoons and embayments before Upper Cretaceous time. The sedimentary origin of the salt would seem to be definitely fixed by the discovery of fossil algae and potash in salt from the Markham dome as announced in this paper. This period of deposition cannot be fixed definitely as older than Lower Cretaceous; indeed, such scant evidence as we possess has a decided Lower Cretaceous complexion, and the authority of so eminent a geologist as Dr. Schuchert is definitely opposed to carrying the age of the salt back to an earlier date.

The salt, anhydrite, and the sediments with which they were interbedded were closely folded by orogenetic movements. Flowage of the salt under compression produced salt structures, which were probably of an anticlinal ridge type, similar to those of the Harz Mountain (Stassfurt) region of Germany. This period of folding is regarded by the writer as essential to the formation of the salt structures, and as it must have been more intense than any of the structural disturbances which have been found thus far in the Cretaceous and younger rocks of the Gulf Coastal plain, this period of folding is believed by the writer to belong to pre-Cretaceous, probably Paleozoic, time and is the basis for his inclination to regard the salt as of pre-Cretaceous age. This view is further supported by the parallelism of the salt-dome alignment to the old Appalachian folding and to the old Arbuckle-Wichita folding.

The entire area of salt structures was submerged and a blanket of some thousands of feet of strata of Cretaceous, Tertiary, and Recent age was deposited upon it. The salt cores of the structures continued to flow, and breaching the old anticlines in which they were first formed, some of the more active cores were forced upward into the almost level-lying blanket of younger rocks. In their penetration of the younger rocks, the salt masses were restricted to a conical form of almost circular plane section, the form of easiest flow and least wall friction. The younger rocks immediately over the salt cores were punched through the overlying rocks and, in instances, lifted thousands of feet. The sedimentary rocks adjacent to the salt core were tilted upward into funnel-like structures dipping away from the salt in all directions. Resistance afforded by the pierced sediments resulted in the blunting of the top of the cone—even a mushrooming as at Vinton, Anse le Butte, Keachi, and other domes. Through continual solution of the upper part of the salt core, eaten away by circulating waters, the anhydrite, originally present as disseminated granules in the salt as in the salt bands of the Five Islands, or interbedded as at Brenham and perhaps at Markham, was left as a residue which formed the cap rock. By hydration, part of the anhydrite became gypsum and some of the gypsum, in turn, by the reaction with circulating mineral waters and organic material was altered to limestone and sulphur or sulphur gases.

The petroleum and natural gas that is found on so many of the salt domes is thought to have accumulated after the formation of the dome. The effect of the dome was merely to afford a type of structure favorable for the accumulation of oil and gas, and the accumulation took place by the normal processes by which it takes in the more ordinary oil and gas structures, with the exception, however, that upward migration across stratification was much more important than in the ordinary types of oil and gas structures.

DISCUSSION

C. S. Schuchert: I have listened with a great deal of interest to what has been said in regard to the salt-dome structures and the various theories seeking to explain the origin of the coastal salt domes. If their origin is to be explained as due to tectonic or volcanic causes, and the salt of the domes is deep-seated bedded salt that has risen into domal structures, then historical geology and times of crustal movements enter into the solution of this most vexed problem. While I have nothing of a definite nature to offer, I want to call attention to several probabilities of a paleogeographic and historic nature that may help toward solving how and when these domes originated.

Because the salt of the domes in North Germany is of Permian origin, there is a widespread feeling among petroleum geologists that there are also Permian formations with salt beneath the coastal domes. For this conclusion I do not find in the paleogeography of North America the slightest evidence. The lay of the Paleozoic formations of the mid-continent oil fields all point to an eastern borderland (Llanoria) throughout the eastern part of Texas, western Louisiana (Sabine uplift), and southern Arkansas during this era. This was the land that furnished the tremendous thicknesses of Pennsylvanian sediments in Arkansas, Oklahoma, and Texas. It appears that within the United States, Llanoria remained land until at least the close of Comanchian time. This is indicated by the paleogeographic maps in the second edition of my *Historical Geology*. In my studies I see no possibility of marine salts in the region of Llanoria earlier than Comanchian time, and now that red strata of Lower Cretaceous age are known in northeastern Texas, and anhydrite in Louisiana, why not beds of salt of Cretaceous time?

Borderlands are periodically rising masses and are more apt to be studded with volcanoes that the areas of epeiric seas. On the other hand, it is well known that during Upper Cretaceous time the seas of Texas had active volcanoes, and why not also the borderland Llanoria? Furthermore, as Appalachia was repeatedly raised vertically during the Mesozoic, why should not Llanoria during the early Cenozoic have been repeatedly faulted, and the blocks let down variously into the developing Gulf of Mexico? The latter appears to have been started in Mexico during late Jurassic time, in Texas during the Lower Cretaceous, and certainly in the western gulf area toward the close of the Mesozoic era.

On the basis of the foraminiferal studies of the Houston paleontologists, it is now known that some of the coastal salt domes came in after Jackson time, that the earlier Oligocene marine strata pinch out against these domes, and that the later strata of the same series completely crossed them. Certain domes appear to be of younger origin, and it is thought by some geologists that yet other domes are still in movement. It occurs to me that there may be many salt domes of early Cenozoic origin that lie buried beneath the very thick Miocene strata.

I therefore offer the hypothesis that the salt domes are due to faulting of old Llanoria during Cenozoic time, and chiefly previous to the Miocene, and that Cretaceous beds of salt are beneath the domes, and that they have risen due to differential block faulting and pressure. As the faulting is in the ancient mass of Llanoria, the fault lines are obscured by the overlying Cenozoic strata, and accordingly there is a lack among the salt domes of definite trend lines. In this connection, attention may be called to the very suggestive paper by Fohs and Robinson on "Structural and Stratigraphic Data of Northeast Texas Petroleum Area."[1]

Subsequent to writing the foregoing, I received a letter from G. D. Harris, calling my attention to his paper of 1909 in *Economic Geology*, and concluding with the following:

> Every bit of dome matter, so far as I know, is highly crystalline, whether lime, gypsum or sulphur. Who ever saw a piece of really *clastic rock* from a dome, much less a fossil? If these rocks are mere fragments of some very low-lying Permian or Triassic horizon, why are they not sometimes clastic? Again, it is rather strange that the salt is often 99 per cent plus pure NaCl. Queer deposit, is it not? that is, if formed as suggested above. Some keen physical chemist some day will find out the cause of "doming."

Even though I had read Harris's most excellent paper at the time of its appearance, I concluded to read it again. This I have now done. I am still of the conviction that the original salt is not older than Lower Cretaceous, and that it may actually be of late Eocene or early Oligocene time. In this connection, I want to bring to the fore what Harris says of epeirogenic movement taking place "at the close of the Vicksburg," and also to the presence of oölitic deposits and red marls that are gypsiferous, accompanying the Grand Gulf sandstones. Furthermore, to the fact that the Oligocene lies in troughs. Therefore I conclude once more that the origin of the salt domes appears to be connected with the inbreaking of the Gulf of Mexico, and that the Mississippi embayment, extending in early Eocene time into southern Illinois, was greatly restricted southward by elevation in the north, beginning markedly in Vicksburgian time. The bedded salt now risen into the domes may be connected with this crustal movement.

J. L. RICH: It would appear to be inevitable that, if salt ridges of anticlinal form such as those of the German area were produced by lateral compression at great depth, and the process of salt intrusion were continued until the salt rose through thick sediments to the surface, it would do so in the form of roughly circular plugs rather than as ridges, for some local point of weakness would develop and the salt would flow toward it from all sides. Therefore circular salt plugs rather than ridges should be expected where the source material lies at great depth.

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[1] *Econ. Geol.* (December, 1923), pp. 709–31.

M. G. Cheney: As to the source of the large amounts of salt needed for the Gulf Coastal salt structures, there are certain considerations which indicate that the late Pennsylvanian and Permian are very possibly the time of these deposits. Llanoria must have been largely base leveled to furnish the Stanley shale, Jackfork sandstone, and early Strawn. Further, the strong overthrusting which produced the Ouachito Mountains and Choctou fault came during Pennsylvanian times and is quite positive evidence of the extensive subsidence of Llanoria to the southeast. Southern Oklahoma changed during the late Pennsylvanian from a generally synclinal to a general anticlinal structure, and the Permian marine waters migrated southward, westward, and northward. Isolation of parts of this southward migrating sea could have led to conditions favoring saline deposits.

G. H. Chadwick: Drilling for natural gas in the southern peninsula of Ontario west of Niagara River has revealed an isolated lens of salt in the Salina formation which domes the overlying Onondaga limestone about 200 feet. This appears to be a true salt dome in youthful stage of growth.

Sidney Powers: I can give additional information regarding this to anyone interested.

Edward Bloesch: The geophysical methods may be helpful in locating and outlining salt domes in the Gulf Coastal region. Some of these, like the seismographic methods, seem to be still in the experimental stage. The gravity method has been used successfully in Europe. The method used in the oil field of Egbell in Czechoslovakia is an example published. Other information on these methods is more confidential and not generally available.

M. I. Goldman: Determination of temperature gradient has been made by Van Orstrand, of the United States Geological Survey, at Damon Mound. I believe he obtained a gradient of something like 70 feet per degree of Fahrenheit. With a little encouragement from this Association and support from the companies here he could probably be readily induced to make more.

THE STRUCTURE OF THE SALT DOMES OF NORTHWEST EUROPE AS REVEALED IN SALT MINES

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ABSTRACT

Salt-mining in Northwestern Europe has afforded significant data on the structure of salt domes. Salt is a relatively plastic rock under pressure, and may "erupt" in a manner analogous to igneous magmas. Highly deformed, clearly traceable key beds in the salt domes of Europe, and progressive changes from slight flowage at the salt outcrops to typical intrusive relations where the salt is deeply buried, afford basis for the conclusion that the European domes are purely tectonic in origin. The cap rock represents the residue of less soluble material in the upthrust salt as solution attacks the rising dome in the zone of active ground-water circulation. The salt domes of Europe are mostly without associated oil deposits, a feature probably due to pre-Eocene erosion which permitted escape of oil from older source beds.

INTRODUCTION

The following paper discusses briefly the structure of certain European salt domes which have been made accessible to students through the openings driven in the operation of mining for salt.

CHRONOLOGY OF SALT-DOME STUDIES

We have come gradually to realize more clearly that the structure of a complex series of rocks, exposed to tectonic forces, is influenced largely by the comparative rigidity of its component members. Following the pioneer work of A. Heim in 1878 and L. Milch in 1911, European investigators have spent considerable effort on this problem. The work of H. Cloos during the years 1918 to 1921, and, with special reference to masses of rock salt, H. Stille (1910 to 1923), E. Harbort (1910), and E. Seidl (1921) is notable.

THE NATURE OF PLASTIC FLOW

If rocks are classified on the basis of their rigidity, the opposite ends of the series are represented by fully indurated crystalline rocks on the one hand, and fluid magma on the other. The intermediate types are, in order of decreasing rigidity, metamorphics, consolidated or compacted sediments, and unconsolidated sediments. Among the processes which increase rigidity, compressive folding is a potent factor.

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[1] President, Marland Oil Company of Texas.

Rock salt and, to a lesser degree, gypsum and clastic rocks with a salty or gypseous cement possess a surprisingly high plasticity under pressure. If a plastic rock incased between more rigid materials is subjected to sufficient pressure, it reacts by flowing and escapes along lines of least resistance; in other words, it "erupts." Fluid magmas do this in a very conspicuous manner, but the behavior of rock salt is quite analogous and very similar. As shown by E. Harbort, salt "erupts" or "intrudes" as salt plugs which are extraordinarily like volcanic necks in some cases, and like laccolithic intrusions in others. Rock salt is not alone in its magma-like flowage, however; Mrazek has described similar intrusions of saliferous clays in the diapiric anticlines of Roumania; Zimmermann in 1889 noted similar phenomena in gypsiferous Triassic shales in Germany, and F. Ehrman in 1921 observed the same thing in the Atlas of Babors, Algeria.

Plasticity of this character varies greatly with depth: given a sufficient overburden, every rock, even the most rigid granite, exhibits plasticity. This plasticity is quite different from true fusion and is not to be confused with fusion. The more deeply a salt mass is buried, the greater the tendency toward the upward growth of salt "plugs," and the stronger the resemblance between these plugs and true volcanic plugs. Although in this manner isostasy plays an important part in the mechanics of salt-dome intrusion, isostasy alone does not afford a complete explanation of the phenomena. Cloos and Stille have both argued that the weight of the overburden merely makes the salt plastic; in order to move and deform it, tectonic stress also is required.

Stille has also observed the curious fact that during periods of orogenic quiet throughout which pronounced diastrophism (folding and thrusting) is lacking, and only block faulting and slow epeirogenic changes of level are to be observed, the plastic elements of the earth's crust continue to move, or even exhibit an increased tendency toward flowage and eruption. This tendency is especially noticeable during plio-epeirogenic periods, i.e., periods of general submergence, and it applies not only to magmatic materials, but also to bodies of rock salt, which occupy a position intermediate between rigid crystalline rocks and magmas. While Stille showed that the upthrust of salt plugs marked periods of diastrophism, K. Gripp has also demonstrated that deep-seated, true "plugs" of salt also move upward during periods of tectonic quiet. Nevertheless, it should be repeated that lateral pressure is a requisite of salt-dome intrusion. If mere isostasy could develop them, we should find salt domes on the quietly stable continental plateaus like the Mid-Continent area of North America, parts of which, such as the western parts of Kansas, Oklahoma, and Texas, are underlain by great, deeply buried beds of rock salt.

THE CHARACTER OF EUROPEAN SALT DOMES

Figures presented by E. Seidl on the salt deposits of Northwestern Europe show in detail the deformation of the salt masses as revealed by extensive potash-mining. Because the valuable potash salts occur in thin beds intercalated with thicker zones of less valuable sodium chloride, mining engineers were obliged to pay especial attention to the structure and deformation of the salt plugs. This work was facilitated by the fact that the salt bed in question, which forms a great blanket deposit of Permian age, extending from Poland to the midlands of England, contains regular and easily distinguished alternations of anhydrite and clay. Particularly useful key beds of this nature are the thick anhydrite and gray clay, 150 feet in thickness, which separates the "upper salt," 600 feet thick, from the "lower salt," 900 feet thick.

The basins along the northern margin of the Paleozoic plateau of Central Europe and the great geosynclinal region of the North German and Baitic plains afford an opportunity to study the structure of salt masses under varying overburden, from the outcrops of the salt beds themselves against the older plateaus, to salt plugs which are squeezed up from depths of 18,000 feet. The structural types form an uninterrupted and continuous series, from slight deformations or flowage on the outcrops, to truly eruptive necks of salt in the region of Hamburg.

At the outcrops the salt merely flows out: the bed thickens where the overburden fails; while down the dip, where the weight increases, the material flows toward the outlet and the thickness of the salt bed decreases.

Where there is no natural outlet toward an outcrop, the salt escapes only at points of weakness. It forms truly laccolithic intrusions, taking advantage of points of weakness, entering the fault fissures, and forcing itself up in them, bulging and finally piercing the overlying strata. If an actual neck forms, it makes room for itself by pushing the sediments to one side and overthrusting the upper strata over the lower. At the same time salt continues to be fed into the plug from below, flowing into the base of the plug from all sides out of the Permian salt bed, which thins and sometimes is entirely squeezed out. These movements within the salt are made manifest by the contortions of the well-defined key horizons noted above. The cores from diamond-drill holes which were sunk through all the salt and into the underlying beds reveal all the salt, down to the base, contorted at high angles, but the underlying bedrock is horizontal.

THE NATURE OF CAP ROCK

Cap rock represents the residue from solution of the salt. As soon as the rising plug of rock salt nears the surface and enters the zone where subsurface waters are in motion, the upper part of the salt begins to go into solution. The top of the salt plug is evidently a solution plane. The folds in the salt mass are planed off sharply by it. We may compare it to the lower end of the glacier, where fusion balances the supply of ice. The top of the salt is the plane above which solution balances the up-push of salt from below. The least soluble impurities are concentrated to form a cap over the rising plug. Consequently, the thickness of the cap depends upon the amount of impurities contained in the salt dissolved, and upon the amount of upthrust after the zone of dissolving ground water is invaded by the upper part of the plug. In Europe the thickness of cap rocks varies from a few inches to 300 feet.

The character of the cap rock depends upon the nature of the impurities of the salt; it may be dolomite, anhydrite, or clay. Limestone or chalk overlying the salt may be altered to calcium sulphate by sulphuric gases or waters, which are often associated with these structures. The cap rock itself may again be corroded by subsurface water, as is the case in many of the German salt domes, where large cavities so formed and filled with brine or quicksand caused great difficulty in the sinking of mine shafts.

The entire structure is so clear that there remains no vestige of doubt as to the origin of these European salt domes and *their purely tectonic nature.* We can follow the evolution step by step in the salt mines of Northwestern Europe.

OCCURRENCE OF PETROLEUM

The German salt domes are but rarely petroliferous. The most important oil field connected with any of them is that of Wietze. The primary source of the oil is probably in the Jurassic and Lower Cretaceous, from which various overlying sand beds have been impregnated. It must be assumed that many of these domes originally carried oil; however, most of them were subjected to active erosion before the deposition of the Eocene, so that the Upper Cretaceous covering of the oil-bearing formations was cut through and removed.

PETROGRAPHY OF SALT DOME CAP ROCK[1]

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ABSTRACT

Two kinds of cap rock are differentiated: the gypsum anhydrite-cap and the calcite cap. The gypsum is derived from the anhydrite by hydration and is characteristic of the upper part of the cap, where it contains much calcite and sulphur. The deeper, less altered part of the anhydrite cap shows parallel banding, which may be the result of diffusion, and breccia fragments of a parallel-banded, finer-grained anhydrite, which give evidence of sedimentary origin. Therefore, although no detrital minerals have been found in specimens of anhydrite cap, this cap is believed to be of sedimentary origin, brought up by an intrusive salt plug from depth. Possible explanations of the presence or absence of anhydrite caps on salt domes are offered. The calcite cap is the product of replacement and penetration by calcite of the sedimentary beds adjacent to the gypsum-anhydrite cap and probably of the upper part of the gypsum-anhydrite cap itself. The sulphur in cap rock is characteristically associated with this calcite. The calcite and sulphur are probably the result of reduction of the outer parts of the anhydrite cap by hydrocarbons from adjacent beds. Constituents of minor importance are sulphides, carbonates of an early generation, barite, celestite, bipyramidal quartz crystals, and inclusions of sandstone in anhydrite.

THE TWO TYPES OF CAP ROCK

The cap rock of the Gulf Coast salt domes is of two kinds, which may be defined as the calcite cap and the gypsum-anhydrite cap. The calcite cap has generally gone by the name of "limestone" cap, but for reasons that will appear, the writer prefers to call it calcite cap.

THE CHARACTER OF THE GYPSUM-ANHYDRITE CAP

An unusually complete core of gypsum-anhydrite cap was very generously lent to the United States Geological Survey by the Union Sulphur Company. This is a practically complete 2-inch diamond-drill core taken between the depths of 670 and 1,468 feet, an interval of about 800 feet, in the company's well No. 194, near the center of the cap-rock area at Sulphur Mine, Louisiana. The core is said to have begun just below the productive rock—that is, probably about at the base of the calcite cap, into which it grades in its upper part—and to have ended on the salt. On account of its gradation to the calcite cap, it will be taken as a basis for the study of both types of cap rock. The general character of this series is brought out by the first piece of core in it (Fig. 1), which contains all the dominant constituents of the series—gypsum, anhydrite, calcite, and sulphur—in their characteristic relations. A detailed consideration of this piece will therefore prepare the way for a more rapid review of the rest of the series.

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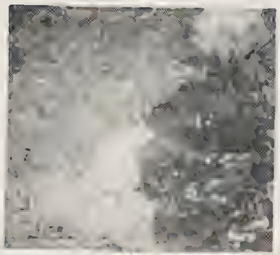
[1] Published by permission of the Director of the U.S. Geological Survey.

The hand specimen appears to be almost pure, dark grayish-black translucent gypsum with traces of banding at a low angle and with slight veinlets of calcite running into druses, in one of which a crystal of sulphur can be seen.

The thin section (Fig. 2) shows large gypsum crystals made up of small elements that have nearly the same orientation. At one end are many disseminated calcite crystals, undoubtedly adjacent to one of the calcite veins (Fig. 4); at the other end, much residual anhydrite (Fig. 6), some of the crystals of which have common orientation with one or more adjacent crystals. This common orientation (which does not appear in the area included in Figure 6) and the corroded outline of the anhydrite crystals, as compared with the rectangular form which characterizes them in typical anhydrite cap rock, constitute the only evidence in support of the assumption that the gypsum of this specimen is derived from the hydration of a rock made up originally of anhydrite. This derivation will be more conclusively demonstrated by subsequent illustrations from deeper parts of this same core (cf. Figs. 9 and 10).

In Figure 6, the line of dark impurities lettered *b* marks the boundary between the two elongated gypsum crystals numbered 2 and 3 in Figure 2. On each side of this line, the entire area represented is essentially a single gypsum crystal. This brings out the fact that here, as usual, a single large gypsum crystal replaces several smaller crystals of anhydrite, apparently owing to a molecular mobility of gypsum which results, it may be supposed, from its solubility. This causes a tendency toward arrangement in common crystallographic orientation with crystals adjacent to it. The common orientation of crystals, parallel to the banding, is undoubtedly due in part to pressure. Even the three major gypsum crystals that make up the section shown in Figure 2 have extinction positions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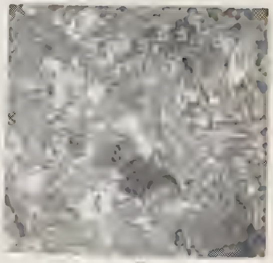
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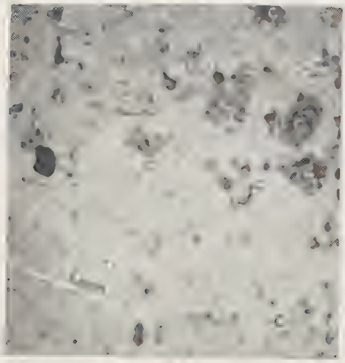
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FIG. 1.—Dark gray translucent gypsum, with open fissure partly lined with calcite and merging into calcite veins.

At *v* calcite veins in solid rock. At *b* banding at low angle of dip, due to planes of weakness. At *s* a single sulphur crystal in an open fissure. Core from 670 feet in well 194 of the Union Sulphur Company, at Sulphur Mine, Louisiana. First piece of core in the series.

FIG. 2.—Thin section from specimen of gypsum shown in Figure 1, crossed nicols

1, 2, and 3 are the three principal crystals that make up the section. Note how near 2 and 3 are to simultaneous extinction. In 1 note the slightly patchy extinction in many small areas with more or less rectilinear boundaries and differing only very slightly in extinction position. This does not refer to the bright white elements scattered about especially in the lower right-hand corner, most of which are fragments broken loose in grinding the section.

FIG. 3.—Remnants of gypsum (*g*) in a matrix of fine-grained calcite

s marks two adjacent remnants of gypsum with simultaneous extinction indicating that they were at one time continuous. Thin section of a specimen from a depth of about 1 foot below that of Figures 1, 2, 4 and 6. Crossed nicols.

FIG. 4.—Calcite crystals (*C*) in gypsum

Detail of the thin section shown in Figure 2, crossed nicols. From the concentration of the calcite in this neighborhood, it is very probable that a calcite vein occurred just outside the area covered by the thin section.

g marks gypsum crystals oriented differently from the surrounding area. No attempt has been made, of course, to indicate all the calcite crystals that can be seen in the illustration.

FIG. 5.—Sulphur (*s*) penetrating fine granular calcite

Thin section from a specimen just below that of Figure 3. Note at *c* the calcite crystals, like those of the matrix, surrounded by sulphur. *g* marks gypsum crystals. Almost all the other clear spaces are holes in the thin section.

FIG. 6.—Remnants of anhydrite (*a*) in the midst of gypsum

Detail of another part of the thin section shown in Figure 2. The gypsum crystals in which the anhydrite occurs are those marked 2 and 3 in Figure 2, and *b* marks the boundary between them. *h* marks holes in the thin section, *h a* apparently one from which anhydrite has been torn. *c* marks calcite crystals.

very near one another, indicating that they are approaching a common orientation. It is important to keep this tendency in mind, for in effect it seems to imply great plasticity in the gypsum; that is to say, if by pressure and movements the gypsum were broken into many small fragments, it would tend to reconstitute itself into large, fresh-looking elements showing no trace of the disturbances it had undergone.

To summarize the phenomena illustrated by this specimen, there is evidence of an original anhydrite rock in which gypsum has largely replaced the anhydrite, single large gypsum crystals taking the place of a large group of anhydrite crystals. Remnants of anhydrite crystals in the gypsum indicate its origin. Fissures and cavities in this gypsum have been veined by calcite, and adjacent to these veins the gypsum has been penetrated and replaced by calcite. A cavity in the gypsum contains a crystal of sulphur. The relation of the sulphur to the calcite is not made clear by this specimen, but evidence to be brought out below will show that sulphur is generally later than the calcite or partly contemporaneous with it.

The paragenetic sequence here, then, is anhydrite, gypsum, calcite, sulphur, and this is the sequence in all specimens the writer has examined.

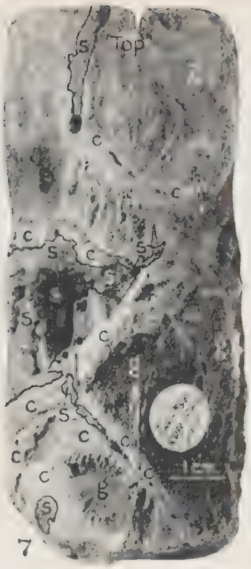
Below the piece of core just described, there is about a foot of gypsum like this specimen, then 2 or 3 inches of a rock in which calcite predominates. That this rock also is derived from a gypsum rock is indicated by the presence, in parts of it, of abundant fragments of gypsum (Fig. 3), which, by their corroded boundaries, by the way they are penetrated by the granular calcite, and above all by the simultaneous extinction of adjacent fragments, indicate that, like the anhydrite in the gypsum of Figure 6, they are remnants of a rock that consisted at one time dominantly of gypsum. Sulphur, in irregular bodies, is common all through this rock. Figure 5, which represents a thin section from the core fragment just below that represented in Figure 3, shows that the sulphur, like the gypsum, is irregularly interpenetrated with the calcite. But there is this difference, that the sulphur includes entirely within its area little calcite masses, so that here it is apparently the sulphur that is later and has come in to replace the calcite.

Although there are no sharp limits to the vertical distribution of different types of rock in this series of core fragments, there is nevertheless a fairly regular development in the character of the predominant type of rock from the top to the bottom, and the differences involved may be most readily grasped if the facts are generalized and the core is described and subdivided somewhat arbitrarily. The subdivisions are represented diagrammatically in Figure 33, p. 83.

The first subdivision may be taken to extend through about 130 feet, from the top of the core at 670 feet to about 803 feet. This part is characterized by the features described above: abundance of calcite as a secondary mineral invading gypsum, which in turn shows scattered crystals of anhydrite, remnants of the anhydrite rock which it has replaced, and the calcite and earlier rock constituents in their turn invaded by sulphur as the latest mineral. Sulphur occurs not only as irregular small bodies within the calcite rock, but also in well-defined calcite veins in the gypsum rock, either filling the central part of the vein or as well-developed terminated crystals lining druses in the veins. The specimen shown in Figure 7 may serve as a type of this part of the section.

The second subdivision of the cap may be made to include the interval of about 150 feet, from 803 to 948 feet. The country rock of this part, instead of being gypsum with scattered crystals of anhydrite, either is anhydrite rock, veined with gypsum that may contain scattered anhydrite crystals, or plainly shows its origin as anhydrite rock by the presence of anhydrite as a dominant constituent in a matrix of gypsum that has clearly replaced anhydrite. Calcite no longer appears as veins or disseminated in gypsum adjacent to veins, but merely as large single crystals scattered through the anhydrite; sulphur veins and the cavities in the rock have also disappeared. In this subdivision and the one below it, the sulphur occurs mainly disseminated through gypsum and anhydrite or as thin films along planes of weakness.

The second division of the section may be illustrated by Figure 9, which shows a specimen from the upper part, at 830 feet. In this specimen the hydration, or more definitely the gypsification, clearly invaded the anhydrite rock along bands presumably of greater permeability. Close examination of the figure shows that there are



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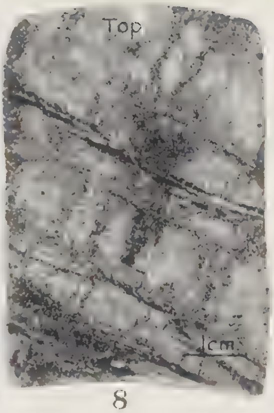

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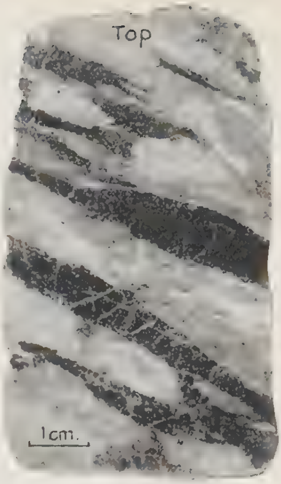

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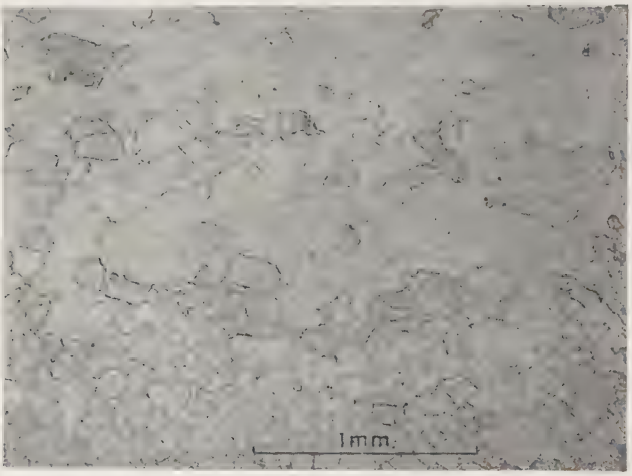

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Fig. 7.—Dark-gray gypsum veined and penetrated by light-colored calcite and by sulphur.

The replacement and penetration of the gypsum, adjacent to the veins, by calcite, is especially well shown. *g* marks gypsum, *c* calcite, *s* sulphur. Exterior of a core from 796 feet in well 194 of the Union Sulphur Company, at Sulphur Mine, Louisiana.

Fig. 8.—Gypsum bands at high and low angles of dip in anhydrite

The darker portions are gypsum of various degrees of purity. Polished face of a core from about 836 ft. in well 194 of the Union Sulphur Company, at Sulphur Mine, Louisiana.

Fig. 9.—Anhydrite interbanded at low angles of dip with gypsum

The dark bands are translucent gypsum; the light bands finely granular anhydrite. Polished face of a core from about 830 feet in well 194 of the Union Sulphur Company, at Sulphur Mine, Louisiana.

Fig. 10.—Contact of a band of gypsum and a band of anhydrite

Thin section from specimen shown in Figure 9. The gray, almost structureless area in the upper part is gypsum, the well-defined crystals are anhydrite.

differences in texture within the anhydrite itself. These are due to differences in size of grain, the denser, whiter portions being the finer-grained. These finer-grained portions of the anhydrite are probably the less altered. The alteration, as in the gypsum, is apparently a result of the solubility of the anhydrite and seems to indicate that water penetrated into the anhydrous rock and, without combining with the anhydrite, partly dissolved and redistributed its molecules. As in the case of gypsum, this tendency of the anhydrite crystals to grow has a definite bearing on the plasticity of the anhydrite, in that it suggests that an anhydrite mass might yield and change its shape by crushing and granulation and yet, on account of this molecular mobility resulting from its solubility, be reconstituted as well-crystallized anhydrite. Under the microscope (Fig. 10) the general structure along the contact of a gypsum and an anhydrite band in the specimen of Figure 9 appears very clearly—a band of solid anhydrite on one side and a band of gypsum with scattered and somewhat corroded anhydrite on the other. Notice, as compared with the gypsum of Figures 2 and 4, the independent development of most of the anhydrite, in the solid anhydrite portion, as chunky, rectangular crystals, each oriented altogether independently of the others except for a slight prevalence of elongation parallel to the banding of the rock.

The gypsum elements in the gypsum band shown in Figure 10 do not have the high degree of common orientation of the gypsum of Figure 6, though most of them extinguish near a position that makes a slight angle with the banding.

In Figure 9, the gypsum bands dip at low angles. Figure 8 shows a specimen from about 6 feet below that of Figure 9, in which the banding by gypsum is at high as well as at low angles. These two distinct directions of gypsum banding occur throughout the anhydrite of this cap, but the low-angle banding is the more common.

In the third subdivision of the section, extending from a depth of 948 feet to the bottom of the cap at 1,468 feet, solid anhydrite is dominant; gypsification is of minor extent, and veining by calcite and sulphur are negligible, although pieces of core obtained within 43 feet of the bottom consist dominantly of gypsum with thin veins of calcite like those near the top, and sulphur in intimate association with this calcite. About 50 feet at the top of this subdivision may be separated as a transition zone, leaving the interval of about 460 feet from 1,004 to 1,468 feet as that in which solid anhydrite predominates.

Three features are characteristic of the anhydrite rock of this third or basal subdivision: (*a*) banding in the mass of the anhydrite rock, dipping at low angles and not due to gypsification, (*b*) evidence of violent brecciation and flowage, (*c*) breccia fragments of a distinctive dense white fine-grained anhydrite that is also banded.

The first type of banding referred to above occurs at irregular intervals. It is present in some pieces of the core and absent in others. The banding takes the form of dark, nearly parallel lines, like bedding lines, running through the granular, sugary type of anhydrite that predominates in the gypsum-anhydrite cap. Some of the bands exhibit a difference in texture accompanied by a difference in color of the anhydrite on opposite sides of the dark lines, dark anhydrite occurring on one side and light on the other. Elsewhere there is a gradation from dark to light anhydrite between two consecutive lines, and in still others a more or less sharp boundary between the dark and light anhydrite occurs without any line between them. Where dark and light anhydrite occur on opposite sides of a dark line, they invariably bear the same relation to the line, the dark anhydrite occurring above it, the light below it.

Figure 8 shows the highest specimen, among those selected for polishing, in which indications of this banding could be recognized, but only by tracing the banding upward from specimens in which it is more definitely developed was it identified in this one. Distinct banding does not appear much above a depth of about 1,200 feet, but is common from this depth to the bottom of the core. The best development of this banding is illustrated by Figure 13. The irregularity of the banding in the specimen shown in Figure 8 is assumed to be due to gypsification, the dark lines being gypsum. The flatness and parallelism of the banding is not perfect in all ungypsified specimens, but is as nearly perfect as much sedimentary bedding.

Brecciation and flowage, the second feature characteristic of the third or basal subdivision of the section, were first noticed in the first specimen in which heavy gypsification ceases and anhydrite becomes a dominant constituent, at about 982 feet. Examples of brecciation and flowage occur from this level down to the bottom of the core, though among the specimens selected for polishing, brecciation and flowage are most common between about 1,250 and 1,300 feet.

The third characteristic feature of this subdivision of the section is the character of the breccia fragments, which consist of a distinctive white anhydrite that is denser, whiter, and finer grained than the anhydrite in which they are imbedded or than unbrecciated anhydrite in general, and that is marked with parallel black lines. These lines, which, like those in the unbrecciated anhydrite, may be due to impurities, appear broader than those in the coarser unbrecciated anhydrite, and the contrast with the dense white anhydrite, which has the same texture and color on both sides of them, makes them stand out more sharply. Figures 12 and 15 illustrate anhydrite of this type in different stages of brecciation and flow. There are some indications that disturbance increased with depth. Figure 14 shows the dense white, strongly banded anhydrite, slightly faulted and with more flow structure than brecciation, in association with the other type of coarser-grained, parallel-banded anhydrite that appears at the bottom of the core. Figure 11 illustrates a more complicated and intimate association of these two types and more extreme brecciation of the dense white rock. As the dense white anhydrite with pronounced parallel banding occurs invariably as breccia fragments in the more coarse granular, darker, more sugary rock, it must be an earlier phase of the anhydrite.

What is admittedly an extremely generalized description of the material from this well of the Union Sulphur Company may be summarized briefly as follows (see Fig. 33, p. 75): There is at the bottom dominantly a pure anhydrite rock in which two forms of structure have been differentiated—a breccia of dense, white, banded anhydrite in a matrix of coarser anhydrite, and parallel low-angle banding in the coarser rock itself. The dense white rock with parallel low-angle banding was nowhere encountered undisturbed. There has been in the coarser-grained anhydrite some gypsification at intervals, some calcification following presumably more permeable layers (as at *c* in Figure 13), and very slight calcite veining, with sulphur in-

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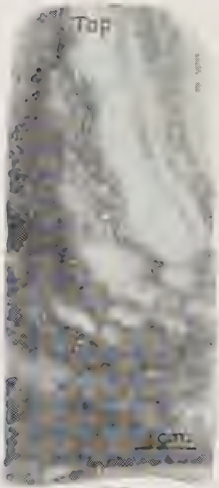

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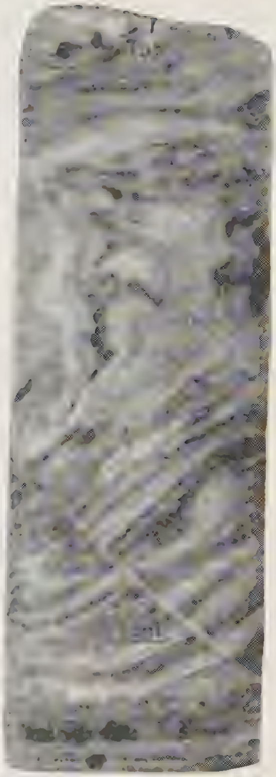

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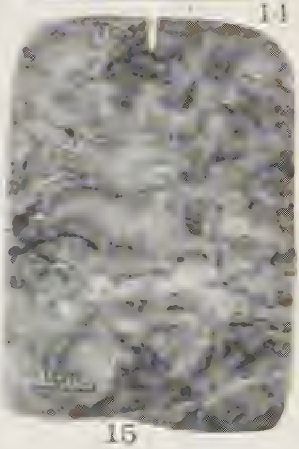

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FIG. 11.—Parallel-banded coarse-grained dark anhydrite interbedded with distorted, dense white, parallel-banded anhydrite.

a marks fragments of dense white anhydrite cut off sharply by overlying bands of coarser anhydrite. Polished face of a core from about 1234 feet in well 194 of the Union Sulphur Company, at Sulphur Mine, Louisiana.

FIG. 12.—Brecciated fragments of banded dense white anhydrite in a matrix of coarser gray anhydrite.

Polished face of a core from about 1197 feet in well 194 of the Union Sulphur Company, at Sulphur Mine, Louisiana.

FIG. 13.—Anhydrite showing well-developed roughly parallel banding at a low angle of dip.

The white patch at *c* is rich in calcite. Polished face of a core from about 1,440 feet in well 194 of the Union Sulphur Company, at Sulphur Mine, Louisiana. As the core lay in the box, the end with this calcite-rich patch is the bottom, but from the relations of the dark and light portions (as explained in the text) in the bands of the rest of the specimen, it is probably the top.

FIG. 14.—Dense white anhydrite with pronounced parallel banding, only slightly distorted.

Coarse-grained anhydrite with parallel horizontal banding just shows at the bottom. The black spots in this coarse-grained anhydrite are gypsum. *ff* marks faults with slight displacement. Polished face of a core from about 1251 feet in well 194 of the Union Sulphur Company, at Sulphur Mine, Louisiana.

FIG. 15.—Dense white banded anhydrite strongly brecciated and distorted

Polished face of a core from about 1294 feet in well 194 of the Union Sulphur Company, at Sulphur Mine, Louisiana.

troduced either adjacent to the calcite veins or in association with calcite along planes of weakness in the rock.

Farther up, gypsification is more common, the gypsum occurring both in bands that dip at low angles, which may be determined by the low-angle banding preserved in the deeper-lying rock (although the gypsum bands lack the pronounced parallelism of that banding), and, less commonly, in bands that dip at high angles, following planes of weakness that must have resulted from bending and cracking either because of upward movement of the salt core or because of pressure produced by the gypsification itself. As the gypsification increases upward, the dark gypsum with remnants of light-gray anhydrite rock floating in it becomes the dominant constituent, until finally the anhydrite can be found only under the microscope as remnants of isolated crystals scattered through the gypsum. With the increase of gypsification, replacement and veining by calcite and sulphur also increase.

In the general form here given, this description probably applies to the rock in its original condition. In some of the calcitic, sulphur-bearing specimens from the upper part of the core, there were conditions suggesting alterations by the water used in the extraction of sulphur, but as the core begins at the bottom of the productive cap, it is probably little altered. Nevertheless, it is very desirable to obtain a core through the entire cap, from some dome on which there has been no extraction of sulphur, or, for that matter, even of oil.

The writer has not studied any other gypsum-anhydrite cap consistently and can therefore not be sure that the general features observed here are those of most other gypsum-anhydrite caps; but from what he has seen, it appears that extensive gypsification in the upper part is general. Some indications of the sharp, parallel, low-angle banding were noted in cores from other domes, and breccia fragments of the dense white anhydrite showing parallel banding—in some fragments much distorted—were seen in material from two other domes. Moreover, it is probably safe to say that where there is a cap over a salt plug, the foundation of the cap is generally anhydrite.

THE ORIGIN OF THE ANHYDRITE CAP

The interpretation of the characteristics described involves the consideration of the origin of the anhydrite cap. The gypsum will henceforth be left out of consideration, as its derivation by hydration of the anhydrite cap seems, in most cases at least, so obvious as to leave no room for doubt.

ALTERNATIVE HYPOTHESES

During this investigation the writer has had in mind four generally recognized hypotheses for the origin of the anhydrite cap: (1) It crystallized from solution, at the top of the salt plug, from underground waters. (2) It segregated as the insoluble residue from the solution, by meteoric waters, of the top of the salt plug as the plug moved up. (3) It was formed by the action of sulphuric-acid water on limestones encountered by the salt plug in its upward passage. (4) It is part of an original sedimentary bed of anhydrite which overlay a bed of sedimentary salt in depth, and as this bed of salt was folded and finally squeezed upward at the apex of the fold in the form of a salt plug, it pushed a layer of the overlying anhydrite ahead of it.

This last hypothesis is the one that is advocated in the following discussion. It is not desired to argue that all the evidence to be presented supports only that interpretation; much of it might be interpreted in favor of another origin. But the evidence has been organized around the hypothesis of sedimentary origin because, taken as a whole, it seemed most to support that hypothesis.

GENERAL CONSIDERATIONS

The most direct reason for assuming a sedimentary origin of the anhydrite cap is that such an assumption is a simple extension of the interpretation of the origin of the salt plug itself from a sedimentary bed—the interpretation that is most commonly accepted on general geologic grounds. A hasty review of stratigraphic sections containing salt beds shows that in a great many sections a bed of anhydrite is found above the salt bed.

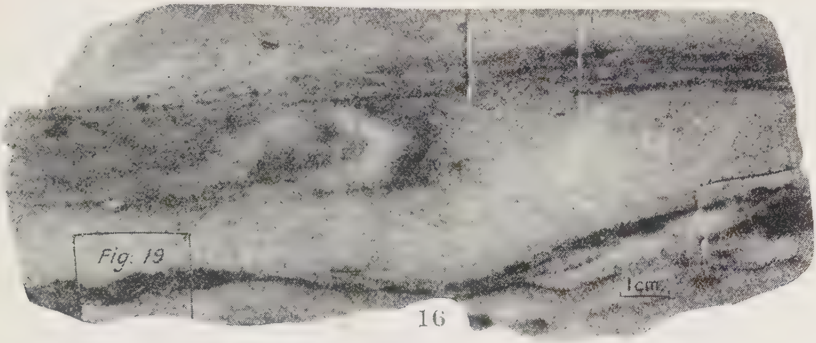
In looking for evidence on the origin of the anhydrite cap, it must be recognized that the cap has evidently undergone extensive alteration and that this alteration may have proceeded so far and through so many different stages as to obliterate all evidence regarding the origin of the cap. The object of the petrographic investigations, therefore, was to determine the character of the earlier stages of the rock. The dense white breccia fragments, as pointed out above, must evidently represent an early stage. As the abundance of these fragments in the deeper part of the core and of the secondary products—gypsum, calcite, and sulphur—in the higher parts suggests that the deeper parts are less altered, it seems that the straight, parallel, low-angle banding of the coarser-grained anhydrite, which is also more common in the deeper parts, may likewise represent an early stage in the formation of the anhydrite cap. The banding of both types of rock will therefore be considered in its bearing on the origin of the anhydrite cap.

ORIGIN OF THE BANDING

Evidence from the larger features as observable in hand specimens.—The mere presence of parallel banding in both these types of material suggests sedimentary origin, but other possible explanations of this banding must be considered.

Shearing and flowage under pressure suggest themselves, but the parallelism and continuity of the dividing surfaces are opposed to this assumption, because a number of specimens of undoubtedly sheared and squeezed anhydrite cap rock, as illustrated in Figures 16, 17, and 18, show contorted and irregularly diverging surfaces and lenticular structure like gneiss and schist. The large, dark inclusion shown in Figure 17 is a fragment of sandstone, and the dark bands in Figure 16, which is a front view of the same specimen, are layers of this same sandstone dragged out with remnants of the bedded sandstone surviving, as shown by the thin section illustrated in Figure 19.

A third possible mode of origin of the banding, suggested by Professor A. C. Lawson in the discussion of this paper when it was presented at the Houston meeting of the Association on March 26, 1924, is that these parallel surfaces might be produced by diffusion accompanied by rhythmic reaction of the Liesegang type, such as can take place in colloids or in any homogeneous medium that permits slow and regular diffusion. The homogeneity of the layers in the dense white breccia fragments, as they appear in the hand specimens, and their resemblance to sedimentary layers afford no evidence that



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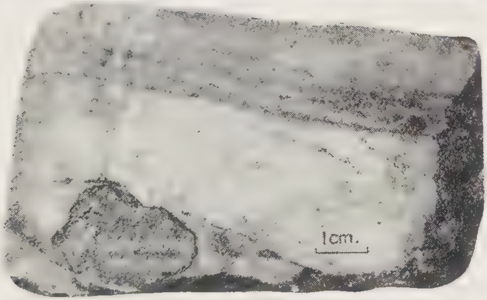

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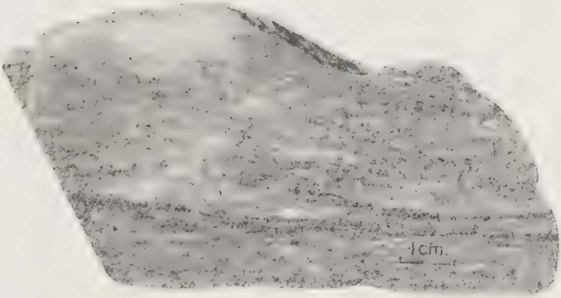

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FIG. 16.—Coarse-grained anhydrite showing flowage

Polished face of a core from 500 feet in the Gulf Production Company's well No. 5, at Hockley, Texas.

FIG. 17.—Reverse side of right-hand end of specimen of Figure 16, showing sandstone inclusion along the black sandy seam in the bottom of Figure 16.

FIG. 18.—Schistose anhydrite

Polished face of a core from 3,055 feet in the Humble Oil and Refining Company's Lizzie Singer No. 3 well on the Palangana salt dome, near Benavides, Duval County, Texas.

might be used in support of this hypothesis, but the parallel bands in the coarser mass of the anhydrite have three characteristic features that may favor it.

One of these features is the close interspersing of these bands with brecciated portions, as illustrated in Figure 11. It may be assumed either that the brecciation took place at the time of deposition, before the overlying undisturbed layer was deposited, or that it took place after deposition, presumably after consolidation and during the tectonic disturbance that produced the salt dome, without disturbing the original sedimentary banding of intermediate layers. The objection to the first assumption is that, as can be seen at the bottom of the specimen illustrated in Figure 11, the parallel banding in the dense white breccia fragments themselves is curved and contorted in a way that it seems likely could result only from great pressure and after consolidation of the fine-grained white anhydrite fragments. The objection to the second assumption is that selective brecciation of such narrow layers seems unlikely in a sequence of material that was probably fairly uniform. These difficulties are met by assuming that this banding is due to diffusion; but, on the other hand, it seems doubtful whether the brecciated material, as illustrated, for instance, in Figure 11, would be uniform enough to yield such straight and parallel bands by diffusion through it. The evidence from this feature in favor of origin by diffusion is therefore doubtful.

The second feature supporting the idea that this banding originated by diffusion is the relation of the banding lines to the fine-grained breccia fragments. In looking over and discussing this series of cores in the laboratory of the United States Geological Survey some time after the Houston meeting, Dr. Donald C. Barton pointed out that the parallel low-angle bands in the coarser-grained anhydrite apparently without exception cut off abruptly the *tops* of the brecciated layers, cutting right through individual breccia fragments of the dense white anhydrite, as can be seen at the points marked *a* on Figure 11. This observation seems to favor the idea that these bands may have been produced by diffusion, though the condition might also be due to solution by the water in which the anhydrite was deposited, before deposition of the overlying bed and after brecciation.

The third feature supporting the hypothesis of origin by diffusion is the change noted above, and shown by Figures 11 and 13, from light-colored material in the top to dark in the bottom of some of the layers. But this feature also might be of sedimentary origin.

Microscopic evidence.—The most conclusive microscopic evidence regarding the origin of the banding is in the fine-grained breccia fragments. The best example is furnished by the core illustrated in Figure 20. This core was in the collection of the late G. Sherburne Rogers, of the United States Geological Survey, who, to the great loss of geology, was drowned while engaged in field work in South America shortly after he began the study of salt domes for the Survey. As no label or record of any kind could be found with this specimen, the writer would be greatly obliged, in case anyone recognizes it, for information as to its origin.[1] The large number of coarse breccia fragments in it and the large proportion of them that show good banding make it unique so far as the writer's experience goes.

In this core the difference between breccia fragments and matrix is sharper than in the Sulphur Mine core, and the parallel banding, with dark seams, is very definite in some fragments, though confused by fracturing and by gypsification along the dark seams in many others. Figure 21 shows a thin section of the best-banded fragment. The evidence from this thin section appears definitely to favor the view that the banding is the result not of shearing by pressure or of diffusion, but of periodicity in precipitation, such as would be expected in a sedimentary bed.

The most obvious bit of evidence is the character of the dark bands themselves. Their dark color is due not to any mere difference in texture or to inclusions like sulphides that might be of secondary origin, but apparently to impurities like clay or other fine detrital matter.

Another fact supporting the idea of sedimentary origin is the slight indication, not recognizable in the figure, of a variation in the coarseness of anhydrite layers from one dark band to the next.

Another is the distribution of the carbonates, which show as dark grains in the figure. These appear to be somewhat more numerous

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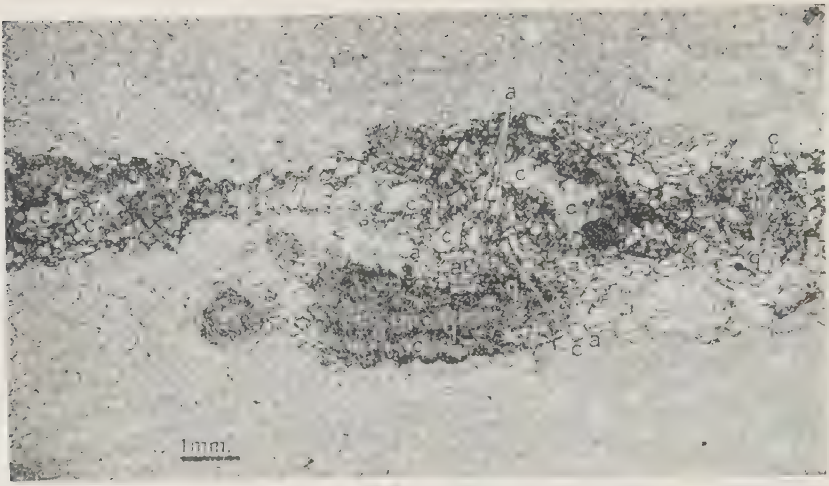
[1] It is possible, though not probable, that this core is not from an American salt dome or indeed from any salt dome.



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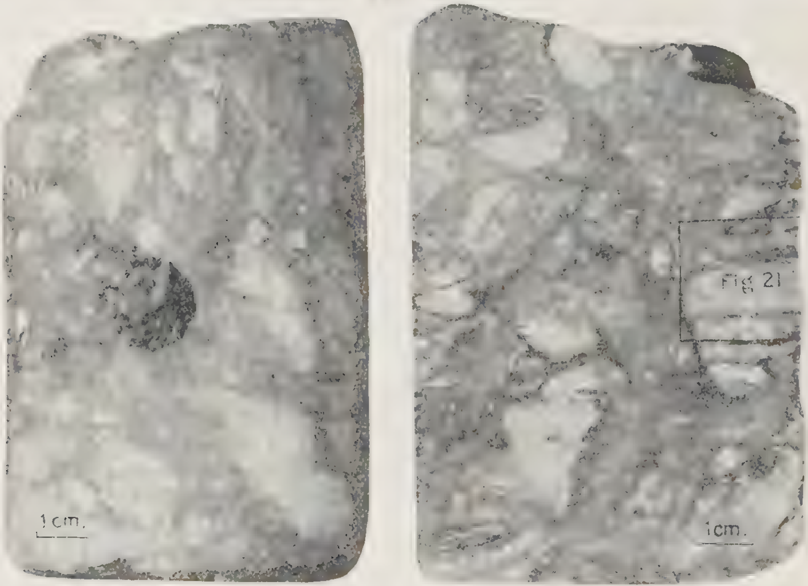

20 A

20 B

FIG. 19.—Thin section of a flowage band of sand in the specimen of Figure 16. The location of the thin section is indicated on Figure 16.

The largest part of the band is calcite (*C*) in large pure elements, and in smaller elements more intimately intergrown with the dark impurity which appears to be mainly sulphide (pyrite?). There are also a number of fragments of anhydrite (*a*), some of them in contrast with the country rock, partly gypsified. The quartz-sand grains are so small and scattered that it was not found practicable to indicate them individually except at *q'*. *qq* indicates sandy bands.

FIG. 20.—Coarse, distinct breccia of very sharply parallel-banded dense white anhydrite in coarser anhydrite.

External face (*A*) and polished face (*B*). Origin of specimen unknown.

on the side of the dark bands opposite the coarser anhydrite than on the other side. If these carbonates had been introduced after the formation of the bands by waters circulating along the bands, they should be equally abundant on both sides.

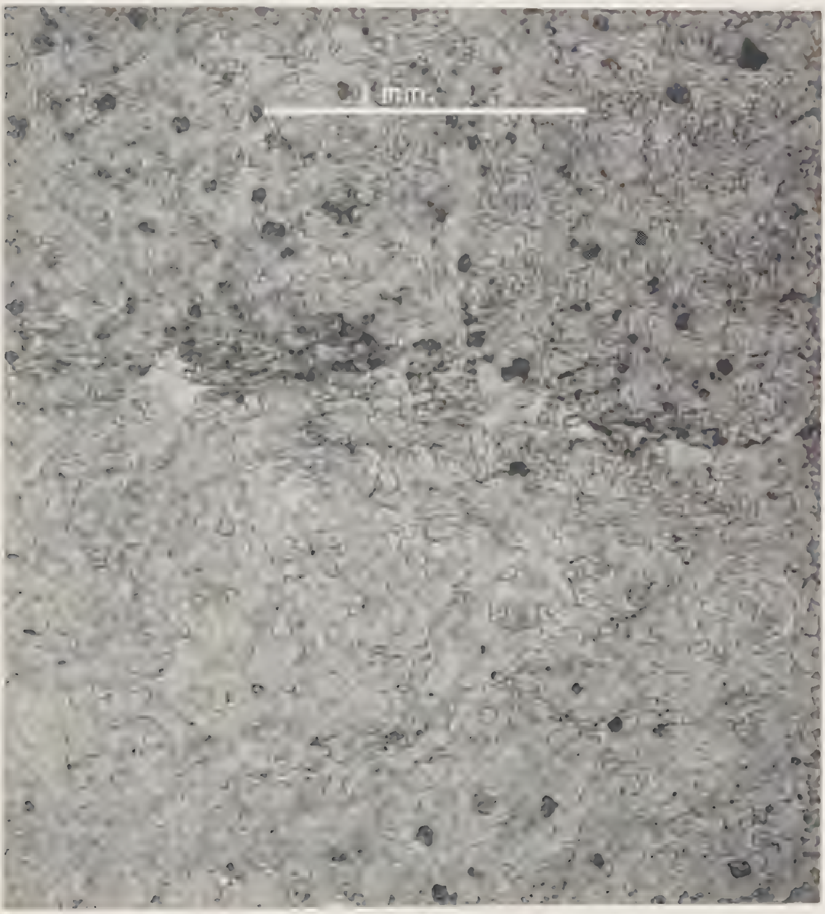

FIG. 21.—Thin section of banded dense white breccia fragment from specimen of Figure 20.

The approximate position of the thin section is indicated in Figure 20

Furthermore, although there are carbonates in both the breccia fragments and the matrix, those in the fragments are mostly dolomite, and those in the matrix are mostly calcite. The dolomite is cloudy and impure looking; the calcite is relatively clear. The dolomite is in distinctly smaller and more regular crystals than much at least of the calcite. Altogether this evidence indicates that the dolomite originated at a different time from the calcite and belongs to a period in the history of the breccia fragments that preceded the brecciation. The presence and the unsymmetrical distribution of these dolomite crystals are just what would be expected in a sedimentary anhydrite rock, for ordinarily the precipitation of the carbonates (dolomite or calcite) precedes the precipitation of gypsum or anhydrite in the undrained bodies of water in which all these substances are deposited, and the more intensive precipitation of the carbonates would have a periodic recurrence with the rainy periods. It is also very probable that the size of the anhydrite crystals precipitated would vary with the concentration of the solution, and in most known examples the crystals grow coarser as the solution grows more concentrated—that is, toward the upper part of a layer. This is the direction of increasing coarseness in the thin section of Figure 21, if the bottoms of the layers are taken to be the parts in which there is the greatest concentration of dolomite.

Support for the hypothesis of sedimentary origin of the banded dense white anhydrite can also be found in the distribution of calcite and anhydrite in a core of banded anhydrite rock of unquestionable sedimentary origin which was kindly supplied by Dr. J. A. Udden. This core (Fig. 24), which came from the Flood well No. 1 in Culberson County, Texas, forms part of a mass of anhydrite over 1,000 feet thick which has been described by Udden.[1] Most of the mass is banded like this specimen. Udden shows that the banding is due to alternate layers of carbonate and anhydrite more or less sharply separated from one another (see Fig. 22), although in some layers the carbonate is less continuous and less definitely limited to a single layer. The carbonate in the thin section illustrated in Figure 22 does not occur in well-defined isolated crystals, as in the breccia fragment of banded anhydrite shown in Figures 20 and 21, but in irregular fragments that lie partly in contact with one another and are elongated parallel to the bedding. Udden illustrates some specimens, however, in which the carbonate is in definite isolated rhombohedra.[1] There is therefore considerable resemblance between the banded breccia fragments of the specimen represented in Figure 20 and this anhydrite of unquestionable sedimentary origin. Although the specimen illustrated in Figures 20 and 21 is conspicuous for the definiteness of its characteristic features, it is probable that the

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[1] Johan August Udden, "Laminated Anhydrite in Texas," *Bull. Geol. Soc. Amer.*, Vol. 35 (1910), pp. 347–54.

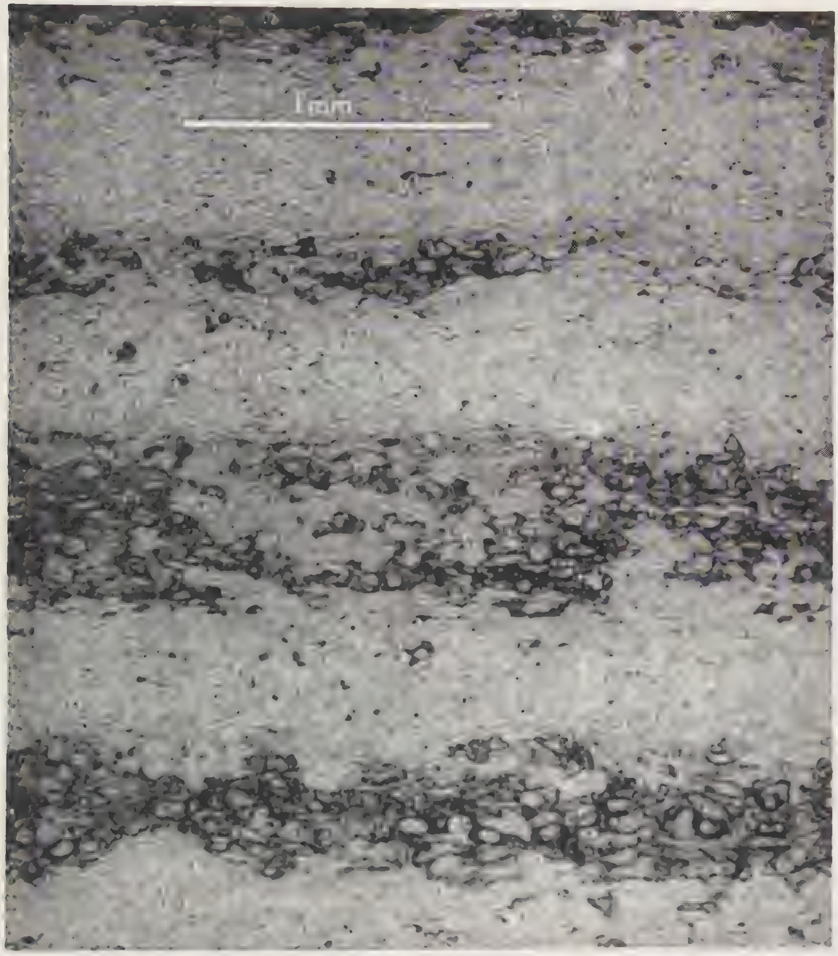

FIG. 22.—Thin section from specimen shown in Figure 24

The dark bands are mostly calcite with much organic matter. The light bands are mostly anhydrite banded dense white fragments in other specimens of the anhydrite cap rock are of the same character.

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[1] See especially Fig. 2 of Pl. 10, p. 351, and Fig. 1 of Pl. 9, p. 350, of his paper.

The remarkable agreement of the microscopic features of the breccia fragments of the specimen illustrated in Figures 20 and 21 with what is found and what would be expected in anhydrite of sedimentary origin points definitely to the sedimentary origin of the original anhydrite cap. These features might perhaps result from diffusion, but in the absence of any definite knowledge as to how they might be produced by that process, it is hard to believe that there could be so close a resemblance between characteristics produced by sedimentation and those resulting from diffusion.

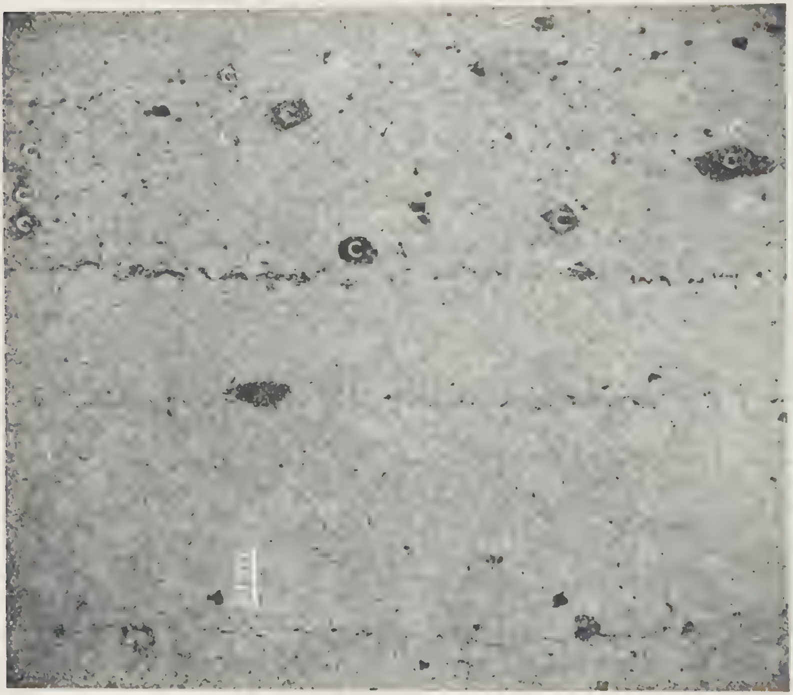


FIG. 23.—Thin section of coarse, undisturbed, parallel-banded anhydrite rock of specimen of figure 13.

c marks crystals of carbonate which, as far as they could be determined, are calcite.

The microscopic evidence for the origin of the low-angle parallel banding in parts of the core that show no brecciation is not so conclusive. Figure 23 illustrates a thin section of material from the specimen of Figure 13. In this section the boundaries of the bands appear very nearly parallel and clearly marked by impurities, but no regular variation in the coarseness of anhydrite crystals across individual bands can be recognized. Carbonate crystals are abundant in some layers, but their very random distribution in the thin section as a whole, the apparently secondary penetration of the rock by calcite as indicated by the white calcareous patch marked *c* in Figure 13, and the general resemblance of these calcite crystals to those found scattered through the anhydrite cap in general and through the matrix of the breccia of the specimen illustrated in Figure 20 make it seem probable that most of them are secondary. If it were possible to differentiate in this rock between calcite and dolomite, the dolomite might be found to be of a different character from the calcite and to have a more definite distribution in the bands; but so far the writer has not been able to make this differentiation. Carbonate crystals of the size of the larger ones in Figure 23 can be recognized easily on the polished face of the core, and by treating these with acid it is easy to prove that they are dominantly calcite. But there are also many small carbonate crystals, some of which are indicated in Figure 23, and it seems significant that these are rather numerous along the surfaces of division between bands, especially along the more clearly defined, more impure portions.

ABSENCE OF DETRITAL MINERALS

One important bit of evidence against the assumption of general sedimentary origin of the anhydrite cap rock is the fact that the residue left by the solution of the anhydrite and gypsum with hydrochloric acid does not seem to contain any detrital sand. It is of course quite conceivable that the basins in which the anhydrite may have been deposited were too large, that the currents in them were too sluggish, or that the cap rocks examined came from localities too near the centers of these basins for sand to have reached them. If further study reveals sand in some anhydrite caps and not in others, and differences in the prevailing size of the sand from different caps, it would pretty well prove the sedimentary origin of the anhydrite cap in general and might make it possible to work out some of the boundaries of the basin or basins of deposition. In the sample from the Flood well, in Culberson County, Texas, sand is abundant and rather coarse; but the bedding in that core was much thinner than the bands in the parallel-banded cap rock, indicating differences in the conditions of accumulation of the two types of rock.

FORM OF THE TOP OF THE SALT MASS

Another feature which casts doubt on the assumption that the anhydrite of the cap was brought up as a bed of sedimentary anhydrite from depth is the supposed form of the top of the salt mass. Evidence is accumulating, from those domes in which enough drill holes have reached the salt, to give the basis for an opinion as to its form, that the top of the mass is quite flat. It seems obvious that such a surface could not result from intrusion of the salt mass, which would yield some sort of convex or irregular upper surface, so that if the salt mass is intrusive, a flat upper surface must be due to some later alteration. Solution by underground water is the explanation that at once suggests itself. If this upper surface of the salt is formed by solution, it is hard to conceive of a cap of anhydrite of sedimentary origin lying directly on it. Perhaps these difficulties cannot only be met, however; they may even serve to account for the brecciated character of the anhydrite cap; for the breccia fragments may be due either to collapse of the cap onto the dissolving salt mass, or they may have existed as included fragments in the dissolved salt. Under either alternative the matrix of the breccia fragments would be derived from solution and redeposition of part of the material of the original breccia. Stages in this process might also account for the parallel banding of the matrix anhydrite.

SUMMARY OF EVIDENCE REGARDING THE ORIGIN OF THE ANHYDRITE CAP

Although the possibility has been considered that the banding in the fine-grained breccia fragments and in the coarser-grained matrix may both be the product of sedimentation, the fragments are necessarily older than their matrix, and their banding may therefore have a different origin from that of the matrix. Three possible causes of the banding in both types of rock have been considered: (1) flowage or shearing, (2) diffusion, and (3) sedimentation. No evidence from the banding of either type of rock favors origin by flowage or shearing. The microscopic evidence from the breccia fragments strongly favors a sedimentary origin of the material of those fragments, and the evidence from the larger features of those fragments, as it affords no clue in favor of origin by diffusion, is also taken to favor origin by sedimentation. The microscopic evidence from the banding in the coarser-grained matrix anhydrite is inconclusive, and the larger features of this banding somewhat favor origin by diffusion, though they can also be explained by assuming that they have resulted from sedimentary processes. Inasmuch as the evidence as to the origin of the anhydrite cap afforded by the banding of the coarse-grained matrix anhydrite does not affect the evidence afforded by the fine-grained breccia fragments, the origin of that cap from a bed of sedimentary anhydrite is indicated.

CONSIDERATIONS REGARDING THE PRESENCE OR ABSENCE OF ANHYDRITE CAPS ON SALT DOMES

If the anhydrite cap is, as suggested above, derived from a sedimentary bed of anhydrite brought up from depth by the salt which it overlay, it is reasonable to ask why it is absent on certain domes which are closely associated with others that have an anhydrite cap. Various possible explanations suggest themselves. One is that those salt plugs which lack anhydrite caps were formed in very sharp folds, which broke the anhydrite and gave the salt a clear passage through. Where that explanation fits the conditions observed the diameter of the salt plug should be small, at least in one direction. Or the anhydrite bed may have been thin and have broken open without very sharp folding. Another possibility is that some of the salt plugs without anhydrite caps were derived from a different salt bed, one perhaps very different in age from that which formed the source of the plugs that have anhydrite caps. The general field relations, such as lines of strike, should indicate whether there is any foundation for such an explanation. The Five Islands, none of which have anhydrite caps, are a group to which this explanation might apply. Another explanation, which would apparently also fit the Five Islands group, is that the anhydrite cap has come so near the surface that it has been dissolved by surface waters. If that has happened, however, it seems as if there should be some residue from the solution. Anything that might be interpreted as such a residue is lacking, so far as known to the writer, from at least some of the Five Islands. Again, the salt plugs without anhydrite caps may be derived from a different part of the same salt bed, perhaps a part that lay nearer the edge of the basin of deposition or in some other locality where the overlying anhydrite bed was thin or lacking. But these are all guesses. What is needed is field observation of the relations of the salt plugs with and without anhydrite caps, and petrographic study of the material directly overlying the salt plugs that have no such caps.

THE CHARACTER AND ORIGIN OF THE CALCITE CAP

Some of the preceding observations afford a basis for a brief consideration of the "limestone" cap, as it is generally called, or the calcite cap, as the writer prefers to call it.

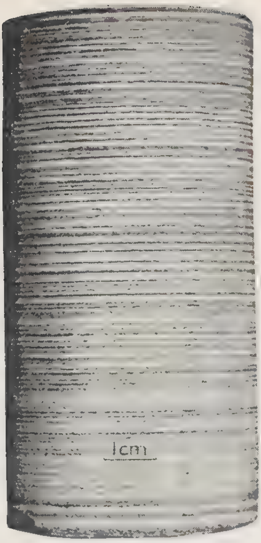
In the core from Sulphur Mine, as was shown above, the gypsum and anhydrite of the upper part of the gypsum-anhydrite cap are veined, penetrated, and in some portions almost completely replaced by calcite. The deposition of calcite, growing more intense toward the upper part of the gypsum-anhydrite cap, no doubt entirely replaced some of the upper portions of that cap and continued into the overlying sediments. It is probably in this way that the calcite cap originated, and it is on this interpretation of its origin that preference for the name calcite cap is based. The term "limestone" has come to mean, to geologists, a rock consisting dominantly of calcite of sedimentary origin. As the writer believes that the calcite of the cap is dominantly of secondary origin, though some of it may be of primary sedimentary origin, the term "limestone" seems misleading.

Reasons for considering the calcite cap essentially a replacement deposit are: (1) the evidences of replacement by calcite associated with veining by calcite seen in the gypsum of the Sulphur Mine core; (2) the evidence from the presence of sand, of calcified bedded sandstone fragments, and of fragments of calcite rocks that differ in texture and structure, some laminated, some homogeneous, that the fragments in or between the vein portions are derived from sedimentary rock of different types. Some of these fragments are undoubtedly derived from the gypsum-anhydrite cap, but where calcification is complete, this fact is difficult to establish and, in any event, is not important in the general interpretation of the calcite cap.

Figures 25 to 28 and Figure 30 illustrate typical calcite cap rock, although these specimens have not been studied microscopically. Figures 25 and 30 show a type in which, it appears, calcite veining has taken place largely along bedding planes as well as across them. Anyone familiar with the marble from Winnfield, Louisiana, will recognize the resemblance between the two. The rock of Figure 26 is veined quite at random, probably because it was more massive than that of Figures 25 and 30, although it shows banding at an angle about like that in Figure 25. Figure 27 is of particular interest because it shows different stages of movement with brecciation and veining. Between the coarse undisturbed calcite veins, which evidently represent the last stage of veining, are masses of brecciated dark rock which themselves contain breccia fragments and veins of an earlier cycle of movement. Some of these breccia fragments containing smaller fragments can be seen at points marked *a* in Figure 27.

Figure 28 illustrates a type of sulphur-bearing calcite cap rock which seems to be characteristic of Hoskins Mound and in which the sulphur occurs as more or less definite bands in the calcite rock. Figure 26 also shows sulphur and gives evidence of its deposition inside of the calcite veins in the last stage of veining. Figure 29 shows breccia fragments of sulphur in a breccia of calcite cap rock. Other specimens give evidence of successive periods of sulphur deposition that followed successive periods of brecciation.

The evidence of successive periods of brecciation in the cap rock is offered because it has been suggested that these breccias might have been formed by collapse of the cap rock into caves occurring in it. Such caves are encountered in drilling. But it seems highly improbable that caves would characteristically form successively in the same place, so that material deposited at the bottom of one cave would later be dropped down into another one beneath. Further-



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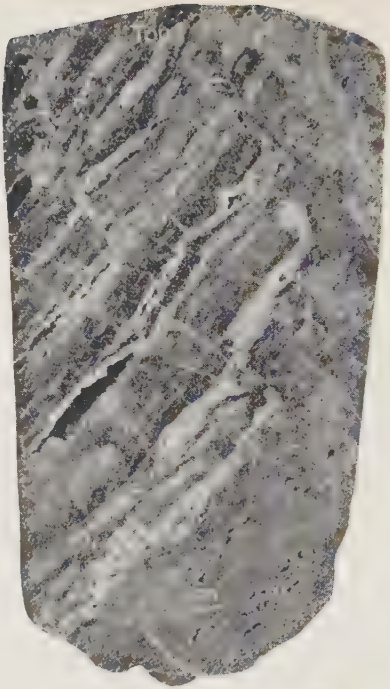

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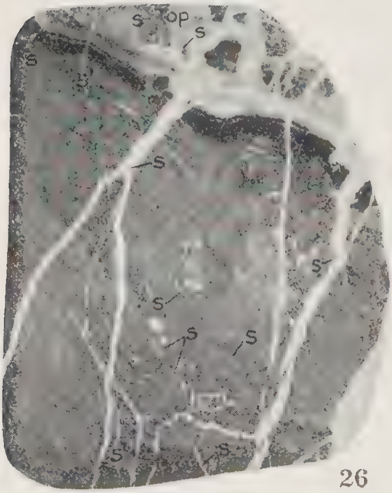

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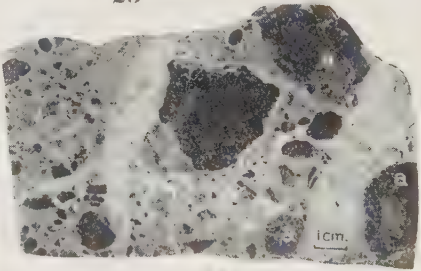

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FIG. 24.—Well-laminated sedimentary anhydrite

View of the outside of a core from 2,131 feet in the David Flood well No. 1, Gresham and McAlpine farm, Block 54, Sec. 42, School Lands, Culberson County, Texas. Received from Dr. J. A. Udden.

FIG. 25.—Coarse white calcite, veined and interbanded with a banded, fine-grained, black calcite rock.

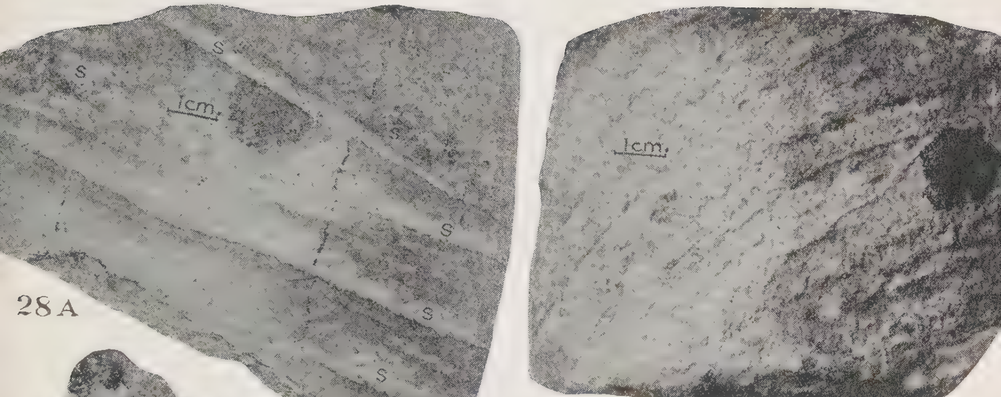
Polished face of a core from 705 feet in well T26 of the Freeport Sulphur Company, at Hoskins Mound, Texas.

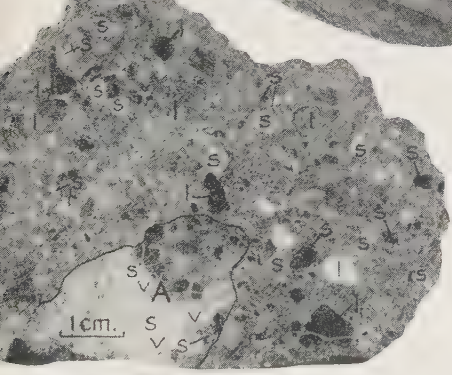
FIG. 26.—Massive, black, fine-grained calcite rock veined with coarse white calcite.

A vague and irregular banding, suggesting flowage, can be recognized. *s* marks occurrences of sulphur. *s′s′* marks a thin vein, partly open, partly filled with sulphur. Polished face of a core from 1,379 feet in well 18 of the Freeport Sulphur Company, at Hoskins Mound, Texas.

FIG. 27.—Breccia of calcite cap rock

a marks breccia fragments which themselves are made up of fragments apparently from an earlier stage of brecciation. Polished face of a core from 1,052 feet in well T 23 of the Freeport Sulphur Company at Hoskins Mound, Texas.





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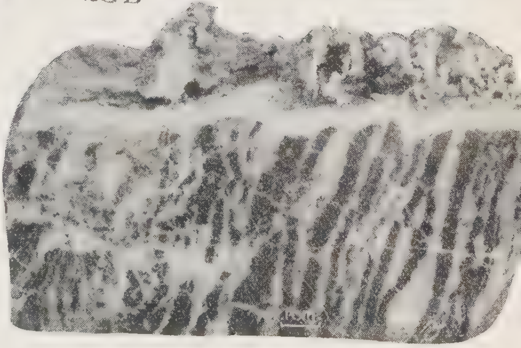

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Fig. 28.—Bands of sulphur in calcite cap rock

Two views of the same specimen, (A) the polished face, (B) the outside surface. In the polished face, the lighter portions are sulphur, as indicated, sporadically, by *s*. The sulphur occurs more or less in well-defined, roughly parallel bands which appear as the raised portions on the outside surface. On the polished face, these sulphur bands can be seen to be accompanied by thin seams of darker calcite, most of which sharply bound one edge of the sulphur bands. Core from 1,295 feet in well No. 2 of the Freeport Sulphur Company, at Hoskins Mound, Texas.

Fig. 29.—Brecciated calcite cap rock full of sulphur fragments

s marks a few of the sulphur fragments. *A* marks what is probably a single fragment in the present breccia, but made up of fragments from an earlier stage of brecciation and cut by a calcite and sulphur vein (*V* and *S*) which does not extend beyond the fragment. The boundary of *A* has been retouched in the illustration. *l* marks some of the breccia fragments of calcite rock. Polished face of a core from well 273 of the Union Sulphur Company, at Sulphur Mine, Louisiana.

Fig. 30.—Similar to Figure 25 with more sharply defined bands

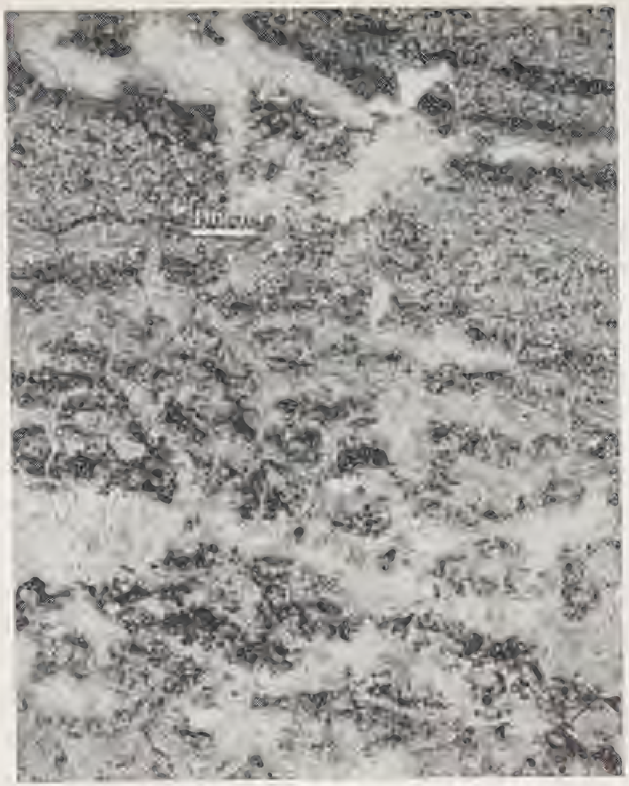
Polished face of a core, specimen 135 of the Texas Gulf Sulphur Company, from Big Hill, Matagorda County, Texas At the top of the figure calcite-lined druses can be seen. The specimen is lying on its side.

more, it seems likely that a cave breccia would contain fewer relatively small fragments and that it would be cemented by coarse-vein calcite rather than by material similar to the breccia fragments. More probably these breccias are the result of crushing by upward movement of the salt plug or by faulting.

The microscopic character of calcite cap rock that is undoubtedly similar to that illustrated in Figures 25, 26, and 30, though represented by chips in which the larger relations could not be seen, is illustrated in Figures 31 and 32. Figure 31 illustrates a type of rock similar on a smaller scale to that of Figures 25 and 30. Vein calcite has penetrated all through a rock which originally was apparently parallel banded. The original rock, in its present condition also composed of calcite, is represented by the darker, less pure, and generally finer-grained portions. The specimen shown in Figure 32 is of particular interest because it includes, parallel to disturbed bands of calcite rock of various textures penetrated by vein calcite, irregular bands of quartz sand also in a calcite matrix. This obviously sedimentary material is 128 feet below the highest specimen of calcite cap and only 50 feet above the highest specimen of characteristic cap-rock anhydrite received from this well.

SOURCE OF THE SEDIMENTARY MATERIAL IN THE CALCITE CAP

One of the most interesting problems regarding the calcite cap is the source of the sedimentary rock in which the calcification has taken place. Calcification of sedimentary beds in place adjacent to the present cap seems to be pretty well established, so that there is good reason for assuming that some of the calcite cap originated near its present position. But if the intrusive origin of the salt plug is accepted, it seems reasonable to assume that some of the material of the calcite cap may have been derived from sedimentary beds encountered in depth by the salt plug in its upward passage. Indeed, on the basis of the intrusive theory, it seems pertinent to ask, as with the anhydrite, If there are no remnants of material of deep-seated origin, what has become of them? In general, the sedimentary material originating at greatest depth should of course occur in the deepest part of the calcite cap. If some of the calcite cap can be proved to



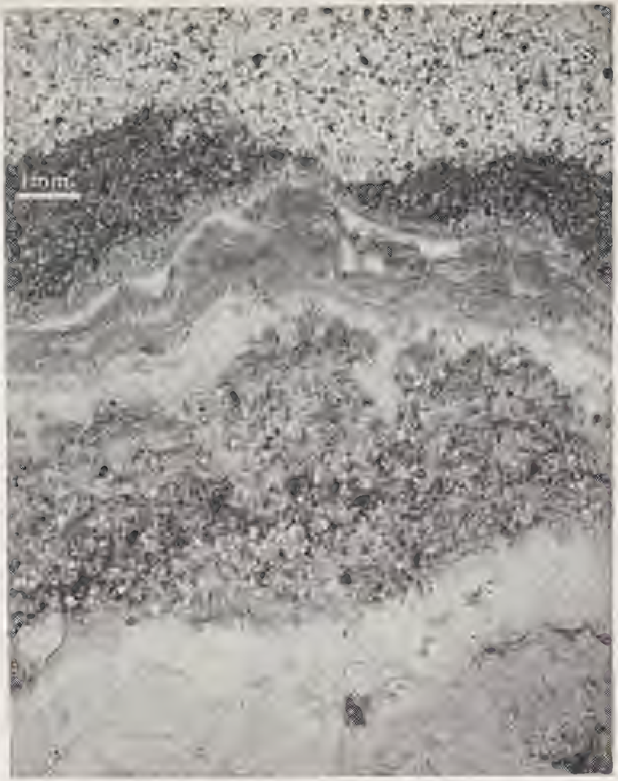


FIG. 31.—Thin section of calcite cap rock, showing penetration of a black-banded rock by calcite

All the rock is calcite, but the perfectly clear parts are apparently [illegible] in blackparts which they vein and penetrate irregularly. From 947 to 948 feet in well 17 of the Texas Company, at Hoskins Mound, Texas.

FIG. 32.—Thin section of sandy calcite cap rock, showing definite banding of a sedimentary nature

[illegible] marks more definitely sandy layers, though, presumably as a result of flowage, the distribution of sand is irregular and not limited to definite layers. From 1,036 to 1,037 feet in well 17 of the Texas Company, at Hoskins Mound, Texas.

come from great depths, the primary sedimentary origin of the anhydrite cap that underlies it would at the same time be proved.

The writer has no evidence contributing to the solution of this problem. Fossils, if there ever were any in the material from which the calcite cap was formed, are not likely to have survived the intense alteration that it has undergone. But there is a nice opportunity here, by using the sandy material in the cap, to see what can be done by mineralogic correlation. This line of attack offers many obstacles, but it seems the best available and if successful would afford valuable evidence on the whole problem of the origin of salt domes.

SOURCE OF THE CALCITE OF THE CALCITE CAP

The source of the calcite which, apparently by veining, cementation, and replacement, has formed the calcite cap is another problem on which little evidence is available from the writer's own observations. The occurrence of the calcite and sulphur in such intimate association above a mass of anhydrite and the abundance of hydrocarbons in the beds adjacent to most domes suggest the obvious idea that the calcite and sulphur are the products of reduction of the anhydrite by the hydrocarbons. Chemically this reaction is quite possible, as is pointed out below in the general statements on the chemistry of cap rock. That it is the reaction by which the calcite cap has actually formed is not proved. The calcite and sulphur bear all indications of having been introduced from outside along veins and planes of weakness and by penetration and replacement in the adjacent rock. Presumably the intense reaction between hydrocarbons and anhydrite would take place at the edge of the anhydrite-gypsum cap, and it is in the outer edge of the cap that sulphur and calcite are said generally to be most abundant. But this relation of calcite and sulphur to the cap is to be expected, whatever outside source they may have had, so that it proves little.

MINOR CHARACTERISTICS OF CAP ROCK

This paper attempts no discussion of features not considered essential to the interpretation of the origin of the cap rock. Among these minor features is the presence of sulphides, which are very common in the anhydrite cap, although in most specimens they occur in small proportion. Another is the presence, in the gypsum-anhydrite cap, of carbonates of a stage apparently preceding the calcification that

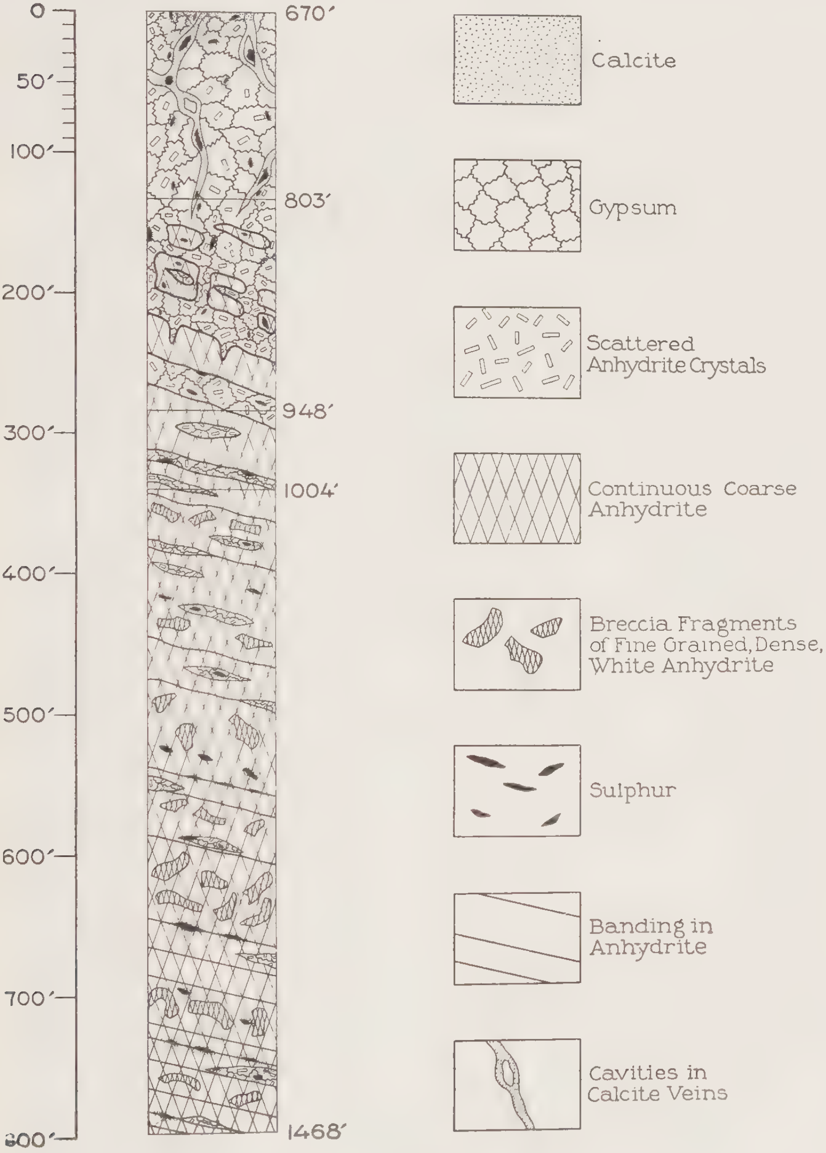

0
50′
100′
200′
300′
400′
500′
600′
700′
800′
670′
803′
948′
1004′
1468′
Calcite
Gypsum
Scattered Anhydrite Crystals
Continuous Coarse Anhydrite
Breccia Fragments of Fine Grained, Dense, White Anhydrite
Sulphur
Banding in Anhydrite
Cavities in Calcite Veins

Fig. 33

produced the calcite cap. Calcite is, as might be expected, the most common of these carbonates, occurring characteristically in well-developed rhombohedra, many of which show growth stages. Dolomite is disseminated as crystals in the breccia fragments illustrated in Figures 20 and 21, but it appears to be scarce; the tradition that dolomite as a rock makes up some cap rocks seems to have no foundation in fact. In one specimen of anhydrite from the Davis Hill salt dome, disseminated crystals of brown sideritic carbonate were common, and in another, of unknown origin, similar crystals were disseminated in intimate association with a sulphide, presumably pyrite.

Other constituents of interest are barite and celestite, the sulphates of the less common alkaline earths barium and strontium, which were found in a number of specimens of the calcite cap.

Very nearly perfect doubly terminated quartz crystals appear to be present in all gypsum and anhydrite cap rock, as they were found in the residue of all specimens of this material dissolved in hydrochloric acid. In most of the rock they are too scattered and scarce to be found in thin sections. Most of them appear quite pure and clear and give no indication of having been derived by the growth of secondary quartz around an original detrital grain of quartz sand. According to Cayeux[1] such quartz crystals are characteristic of gypsum deposits.

Among certain peculiar features that are not discussed in detail in this paper, one of the most interesting and puzzling is the occurrence of large pieces of sandstone or of calcified sand in the midst of anhydrite, as illustrated in Figures 16, 17, and 19. Is this sedimentary sand that was deposited in the midst of sedimentary anhydrite; or did the anhydrite flow around sand or sandstone adjacent to it; or is it secondary anhydrite deposited from solution around the sand?

THE CHEMISTRY OF CAP ROCK

One of the chemists of the United States Geological Survey, Mr. R. C. Wells, when asked to discuss the possible chemical reactions involved in the origin of cap rock, pointed out that there are so many possible reactions that merely to list them would leave the solution of the problem little farther advanced. The geologist must obtain from field observation all possible evidence as to the reactions that seem to him likely to have taken place and then come to the chemist for guidance as to which of these reactions are possible, and which, under the particular circumstances, are the more probable.

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[1] L. Cayeux, *Introduction a l'étude pétrographique des roches sédimentaires*, p. 196. Paris, 1916.

The following simple statements, however, were obtained from Mr. Wells and are offered with his approval: (1) Hydrocarbons (oil, gas, and so on) from the sedimentary rocks reacting with anhydrite or gypsum might very well produce $CaCO_3$ and S or H_2S. In this way sulphur might be separated in depth and $CaCO_3$ removed. (2) Sulphur could go into solution by virtue of a number of reactions, especially at high temperatures—as organic sulphur-hydrocarbon compounds, for instance, or by reaction merely with water, yielding H_2S, H_2SO_4, SO_2, thionates, etc.—or it could be sublimed. (3) The separation of sulphur from H_2S is an oxidation process and would therefore probably depend on the migration of the solution carrying the H_2S to upper levels where it could be oxidized. In this way sulphur might be separated near the surface. (4) Metallic sulphides would be very likely to be formed by H_2S-bearing solutions passing through rocks that contained metallic oxides or metallic carbonates. (5) As the formation of sulphur in the upper zones is likely to depend on oxidizing conditions, the formation of sulphides might well precede that of sulphur in those zones. (6) It is quite possible that barium and strontium sulphates might, like calcium sulphate, be reduced and brought into solution by hydrocarbon-bearing waters, by which they might be transported to regions where sulphates were again in sufficient excess to redeposit them as sulphates. (7) The transformation of anhydrite into gypsum can take place at almost any temperature in the presence of pure water, but in the presence of sea water it could probably take place only at temperatures below 30° C. (80° F.), and in the presence of a saturated solution of NaCl only at somewhat lower temperatures. So far as observations go, it does not seem probable that the temperature of this transformation would be much influenced by pressure, but it obviously is much affected by the presence of dissolved salts.

According to observations by C. E. Van Orstrand, of the Geological Survey, this temperature of 30° would be reached at Damon Mound at a depth of about 900 feet.

In conclusion, it is worth while always to have in mind that different cap rocks or different parts of the same cap rock may have different origins. The evidently complicated history of any specimen of cap rock points that way. Keeping this possibility in mind may avoid some confusion and misunderstanding.

ACKNOWLEDGMENTS

Help in carrying on this investigation has been received from so many sources that it would be impossible to name them all. In fact, the writer cannot recall any company or individual approached that did not appear ready to contribute most generously, so far as business conditions would permit. This occasion is taken, therefore, to express on behalf of the United States Geological Survey, for which the help was of course primarily intended, sincere appreciation and gratitude. This help has come in the form not only of specimens and data but also in the liberal sharing of ideas, so that it would be hard to disentangle from the product what is the writer's own and what he has received from others, and he can merely acknowledge his debt in a general way here. It has been an inspiring example of the best sort of co-operation in a scientific investigation.

GEOLOGY OF THE SALT DOMES[1] IN THE CARPATHIAN REGION OF RUMANIA

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University of Cluj, Rumania

ABSTRACT

The Rumanian salt domes are confined to the axial portions of sharp anticlinal folds and fracture zones which affect the sedimentary rocks of the region. The anticlines are aligned with the Carpathian axes. Intrusion of the salt has been accompanied by intrusion of thick masses of breccia composed of sedimentary and some igneous rocks of all ages, including types of rock unknown beneath these portions of the mountains. Both salt and breccia have been thrust upward in diaper manner and even overthrust with sharp, recumbent crests.

The author believes that the salt in the Rumanian domes cannot be of Miocene age, as has been previously contended, and he argues that the original salt beds from which salt domes have formed, not only in Rumania but universally, are products of the evaporation of the earliest lakes and shallow seas to form on the surface of the primitive earth. These waters were rich in chlorides and other salts taken into solution from the heated rocks of the earth's crust and condensed from the heavy blanket of the earth's atmosphere. Part of the immense quantity of salt deposited in this manner was redissolved in the permanent oceans, but after these had become saturated, the main part of the salt deposit remained, to be covered by the first muds laid down on primitive sea floors. They were thus protected until movement and pressure squeezed the salt upward as salt plugs. The intrusion of the Rumanian salt plugs is late Pliocene or early Pleistocene.

INTRODUCTION

Salt is the most widely distributed mineral in the Carpathian region of Rumania, and when all the salt deposits here are known, there will be few countries that can boast the same richness in salt. Already more than 200[2] salt domes and 350 salt springs are known in this region, the springs indicating the presence of deep salt masses. Besides these, some salt or alkaline lakes are found in the projection of the axis of the southern curve of the Carpathian arc (Plate 1).

To facilitate a clear understanding of the occurrence of the salt domes, it is desirable to undertake first a general survey of the geology of the Carpathian region of Rumania.

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[1] The translation "salt domes" should now correctly read "salt anticline."

[2] The following salt domes of the Carpathian region are now exploited: two in Maramuresh, one in Bucovina, one in Moldavia, one in Muntenia (Wallachia), one in Oltenia, and five in Transylvania. For the mode of exploitation, see Ing. Zernoveanu, "Sarea si exploatarea ei in Romania" ("Salt and Its Exploitation in Roumania"), *Annales des Mines de Roumanie*, 1923.

GEOLOGICAL STRUCTURE OF THE CARPATHIAN REGION

From a geological point of view, Rumania may be divided into two great regions (Fig. 1):

1. *The Carpathian Mountains proper*, in which all the structural Carpathian zones, folded or not, are included, and form a unit.

2. *Areas adjacent to the Carpathians*, containing the structural units of the forelands, namely: (*a*) the Podolico-Russian platform on the east and northeast border of the Carpathians, the frontal parts of which are found today sunken under the Moldavian upland and the Moldavo-Bessarabian depression; (*b*) the Varisco-Kimmerian chain of northern Dobroudja, on the southeast, which in Permo-Carboniferous time formed a continuous mountain chain with the Sudets; (*c*) the Pro-Balkan platform, on the south containing southern Dobroudja and the Pro-Balkans, the frontal parts of which are found today sunken under the Rumanian plain (the plain of Wallachia) and the Getic depression of Oltenia.

These three outer structural units surround in a semicircle the exterior border of the Carpathian arc, and the tectonic movements in them have contributed strongly to the formation of the structure of the Carpathian Mountains.

Since the salt-dome masses as well as the saline springs appear only in the Carpathian province, a brief but detailed description of its geological structure will be given.

THE CARPATHIAN MOUNTAINS PROPER

A general morphological study of the Carpathian Mountains reveals the following tectonic units:

a) *The Old Carpathians*, which, on account of their strong development in the old province of Dacia, are designated as the Dacic chains, are formed of crystalline schists, generally Paleozoic, and old granitic rocks; some areas of less metamorphosed Paleozoic formations, Devonian, Carboniferous, and Permian; and Mesozoic formations, Triassic, Jurassic, and Lower Cretaceous—the bathyal facies, preserved in synclinal troughs in the regions of crystalline schists.

The Dacic chains that once with the central zone of the Alps formed a unit—a central Carpathian block—are now isolated sunken

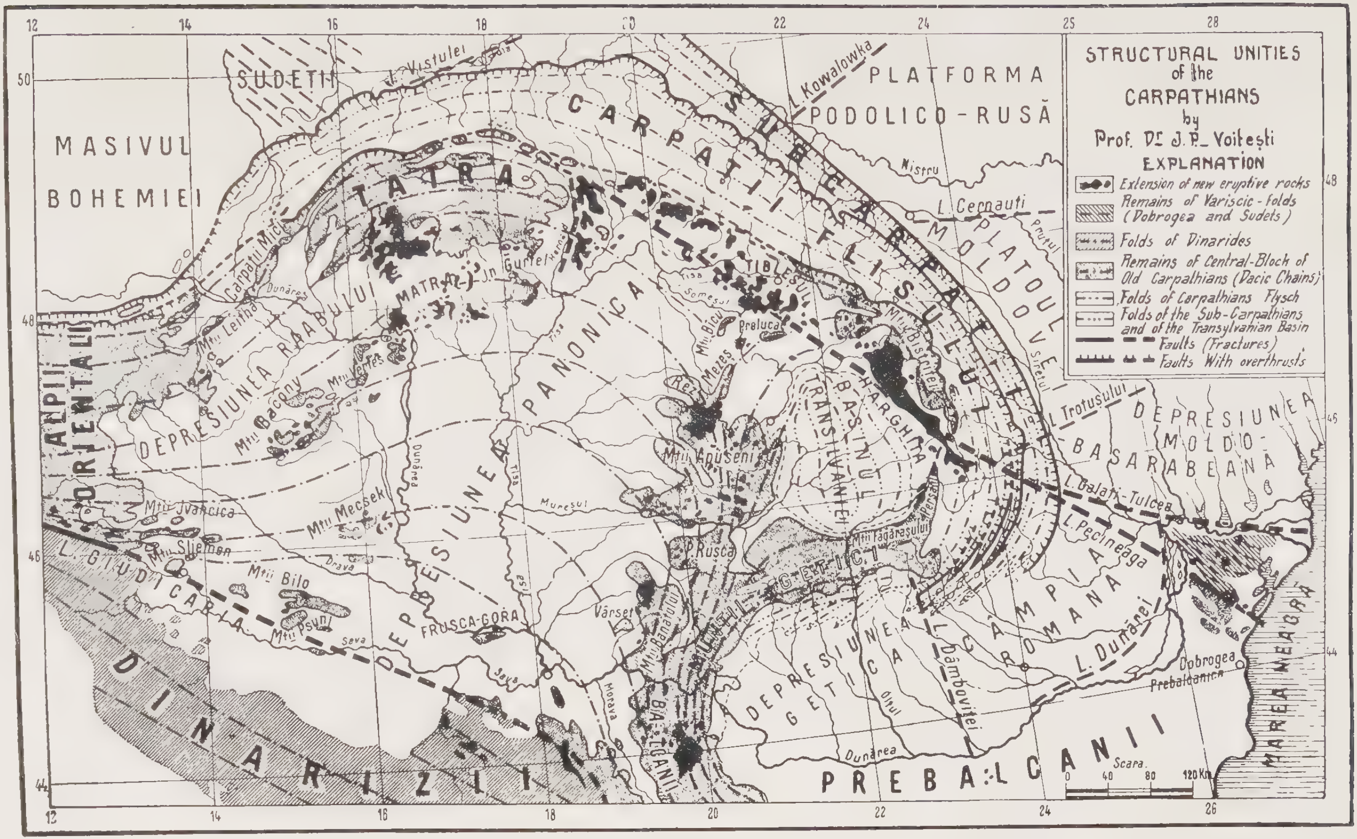
STRUCTURAL UNITIES of the CARPATHIANS by Prof. Dr. J.P. Voitești
EXPLANATION
Extension of new eruptive rocks
Remains of Variscic-folds (Dobrogea and Sudets)
Folds of Dinarides
Remains of Central-Block of Old Carpathians (Dacic Chains)
Folds of Carpathians Flysch
Folds of the Sub-Carpathians and of the Transylvanian Basin
Faults (Fractures)
Faults With overthrusts
MASIVUL BOHEMIEI
SUDETII
L. Vistulei
L. Kowalowka
PLATFORMA PODOLICO-RUSĂ
CARPAȚII
SUBCARPAȚII
FLISULUI
Nistru
L. Cernauti
Prutul
PLATOUL MOLDOVEI
Siretul
L. Trotușului
DEPRESIUNEA MOLDO-BASARABEANĂ
L. Galați-Tulcea
L. Pecineaga
CAMPIA ROMANA
L. Dunărei
L. Dâmbovitei
Dobrogea Prebalcanica
MAREA NEAGRĂ
PREBALCANII
Scara 0 40 80 120 Km
Dunărea
Oltul
DEPRESIUNEA GETICA
GETICI
Mtii Făgărașului
Perșani
HARGHITA
BASINUL TRANSILVANIEI
Mtii Bistritei
TIBLEȘUL
Preluca
Someșul
Tisa
Mtii Bicu
Mezeș
Rez
Mtii Apuseni
Rusca
Mureșul
Mtii Banatului
Vârșet
Morava
BALCANII
TATRA
MATRA
Jn Gurfel
Hernad
Carpații Mici
Mtii Leitha
Dunărea
DEPRESIUNEA RAABULUI
Mtii Bacony
Mtii Vertes
PANONICA
DEPRESIUNEA
Mtii Mecsek
Drava
Sava
FRUSCA-GORA
Mtii Ivancica
Mtii Sljemen
Mtii Bilo
Mtii Psunj
L. GIUDICARIA
ALPII ORIENTALI
DINARIZII
12 14 16 18 20 22 24 25 28
50 48 46 44
26

FIG. 1

segments, disposed in two series of descending steps around the great "Panonic depression" that occupies the central part of the block. The steps are separated by smaller secondary depressions: the Raab depression on the west and the Transylvanian basin on the east.

On the Rumanian side of the Panonic depression, that is, on the east, the first more deeply sunken step is represented by "Muntii Apuseni" (the western mountains). The second, separated from the first by the depression of the Transylvanian basin, is composed of two large areas of crystalline rocks. In the southern Carpathians are the crystallines of the Getic Mountains and those of the Banat, which are connected with the southern part of "Muntii Apuseni" by the "Muntii Poiana Rusca"; and in the eastern Carpathians there are the crystallines of the mountains of Bistritza and Maramuresh.

In all these large or small areas of the central block traces of two periods of folding are in evidence: first, the obscured traces of the Hercynian folding (Mid-Carboniferous) over which the conglomerates of the Permian (Verrucano) transgress; and second, the strong folding, with overthrusts of the Middle Cretaceous that gave the present general configuration to the Carpathian chain.

An effect of these movements was the formation of all the large and small structural depressions on the inner and outer border of the central block that separated various chains. Subsequent epochs of folding have only accentuated these features. In the depressions were deposited the post-Lower Cretaceous formations.

b) *The Flysch zone of the Carpathians* is composed of a broad zone of Cretaceous-Paleogene, deposited in the depression that surrounded the remains of the central block. It was strongly folded in the Oligocene, the Miocene, and at the end of the Pliocene, forming today the high crest of the eastern and northeastern Carpathians.

Toward the southwest the folds in the Flysch, as they approach the great massif of crystallines in the southern Carpathians, pass from the Carpathians to the sub-Carpathians in the form of three anticlinal axes that plunge gradually to the west, squeezed between the great synclinal basins of the Mio-Pliocene that separate them (Fig. 2). These three terminal anticlinal crests correspond tectonically to the three successively superposed overthrusts of the Flysch, disposed in the form of steps, mounting one over the other toward the exterior, the last one overriding the sub-Carpathians. These, in turn,

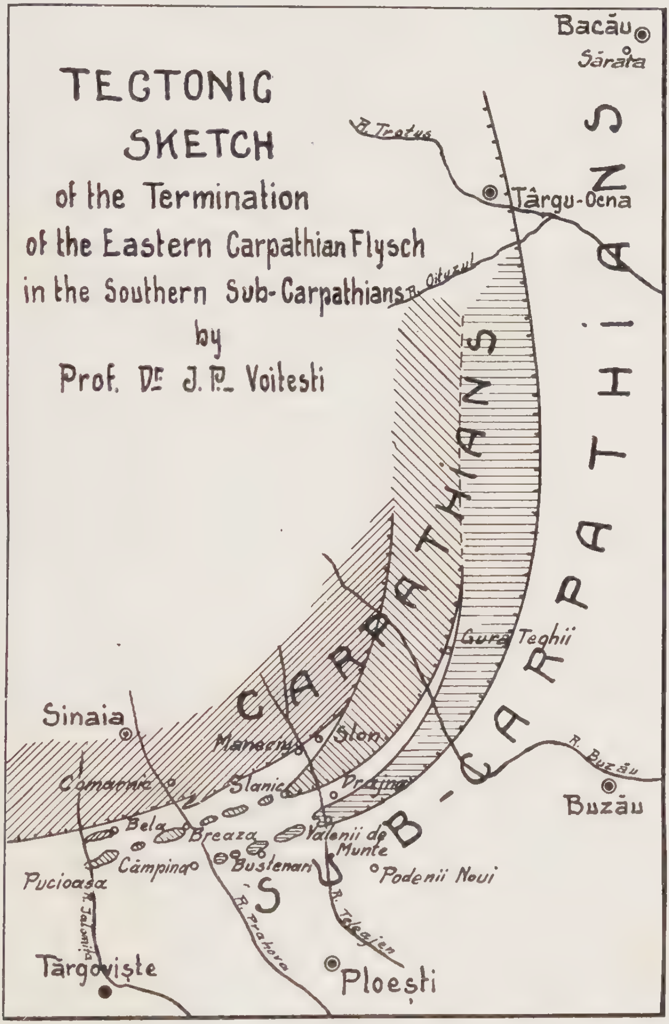

FIG. 2

correspond to the three facies of the Eocene (the interior facies, the facies of Fuzaru sandstone, and the marginal facies) of the eastern and northeastern Carpathians.

c) *The sub-Carpathians*, consisting only of Tertiary sediments, represent the newest system of folds that were added to the Carpathian Flysch at the end of the Pliocene or beginning of the Quaternary, and that surround it completely.

These three great tectonic units of the Carpathian region represent, thus, three zones that were folded at different epochs, the newer being added successively on the exterior of the older.

At the same time each of these tectonic units represents one complete evolutionary cycle (lithogenesis, orogenesis, glytogenesis) of the stages through which the geosyncline of the Carpathians has passed. The geosyncline has been moved outward three times under the influence of the successive sinkings, in the form of steps, of the frontal regions of the forelands.

These outward displacements of the Carpathian geosyncline at different tectonic periods have caused the three tectonic units of the Carpathians (the Dacic chains of the old Carpathians, the Flysch zone of the Carpathians, and the sub-Carpathians) to be disposed in three steps descending outward, separated by lines of strong longitudinal fractures, along which the older and inner overlap the newer and outer ones.

SALT DOMES AND SALINE SPRINGS

RELATIONSHIP OF SALT DOMES TO THE STRUCTURAL ZONES OF THE CARPATHIANS

Very few springs (Plate 1) are connected with the step blocks of the forelands, and these, like the salt springs of the Moldavian upland and those that supply the salt and alkaline water lakes of the Rumanian plain adjoining the southern curve of the Carpathians, contain only a small amount of $NaCl$, though more $NaSO_4$ and $MgSO_4$. The salt domes, as well as the pure salt springs, appear only in the Carpathian region proper.

Aside from the saline and sulphurous hot springs which appear in the fractures bordering the granite of the valley of Cerna at the Baths of Hercules (Banat) and which are surely connected with the post-volcanic manifestations of this region, it is found that masses of rock salt or saline waters occur in almost all the formations underlying the Carpathian regions.

Beginning with the oldest formations, a strong salt spring is found in a fracture of the crystalline mica schists in the mountains of Persani, at Sinca Noua, in the southeastern part of Transylvania.

In the Lower Cretaceous (Albian), salt springs occur at Comarnic, Bertea, and Vulpea, in the district of Prahova; and at Bela, in the district of Dambovita, in the western prolongation of the anticline whose core contains the salt mass of Bezdeadu (Plate 1 and Figs. 3 and 4).

Under the sandstone of the Upper Cretaceous (Cenomanian), a salt mass and two salt springs appear under the peak of Maciucu Bertei (Bertea, Prahova).

In the Paleogene of the Carpathians (Eocene and Oligocene), there are innumerable salt springs and a great many salt domes extending the entire length of the Flysch zone from north of Bucovina to west of the Olt, in the southern sub-Carpathians, and from its exterior to its interior border. The salt masses occur always in the more or less fractured anticlinal crests. In the Flysch of the eastern Carpathians, the salt masses as well as the salt springs are much more numerous in the vicinity of its outer border fault (Plate 1 and Figs. 5 and 6). In the prolongation of this zone in the southern sub-Carpathians the occurrences of salt masses and salt springs are closely connected with the terminal anticlinal crests of the Paleogene that disappear gradually toward the west.

In the Miocene, Pliocene, and even Quarternary, there are many salt domes and springs along the entire length of the eastern sub-Carpathians, from northern Bucovina to their southern curve, and from there westward throughout the southern sub-Carpathians, as far as the valley of Jiu. They are most numerous in the neighborhood of the marginal fracture of the Flysch and of the flexure along the outer border of the sub-Carpathians (Plate 1). Salt domes and springs are also found in the Miocene and Pliocene of the interior of the Carpathian chain, in the Transylvanian basin, where the greatest number of the salt domes seem to be connected with the marginal fractures of the depression, although there are some within the basin, as well as in the Maramuresh (Plate 1 and Fig. 7).

Salt is found even in the great Panonic depression, for at Brustur (Tartaros), on the northwest border of the crystallines of the eastern

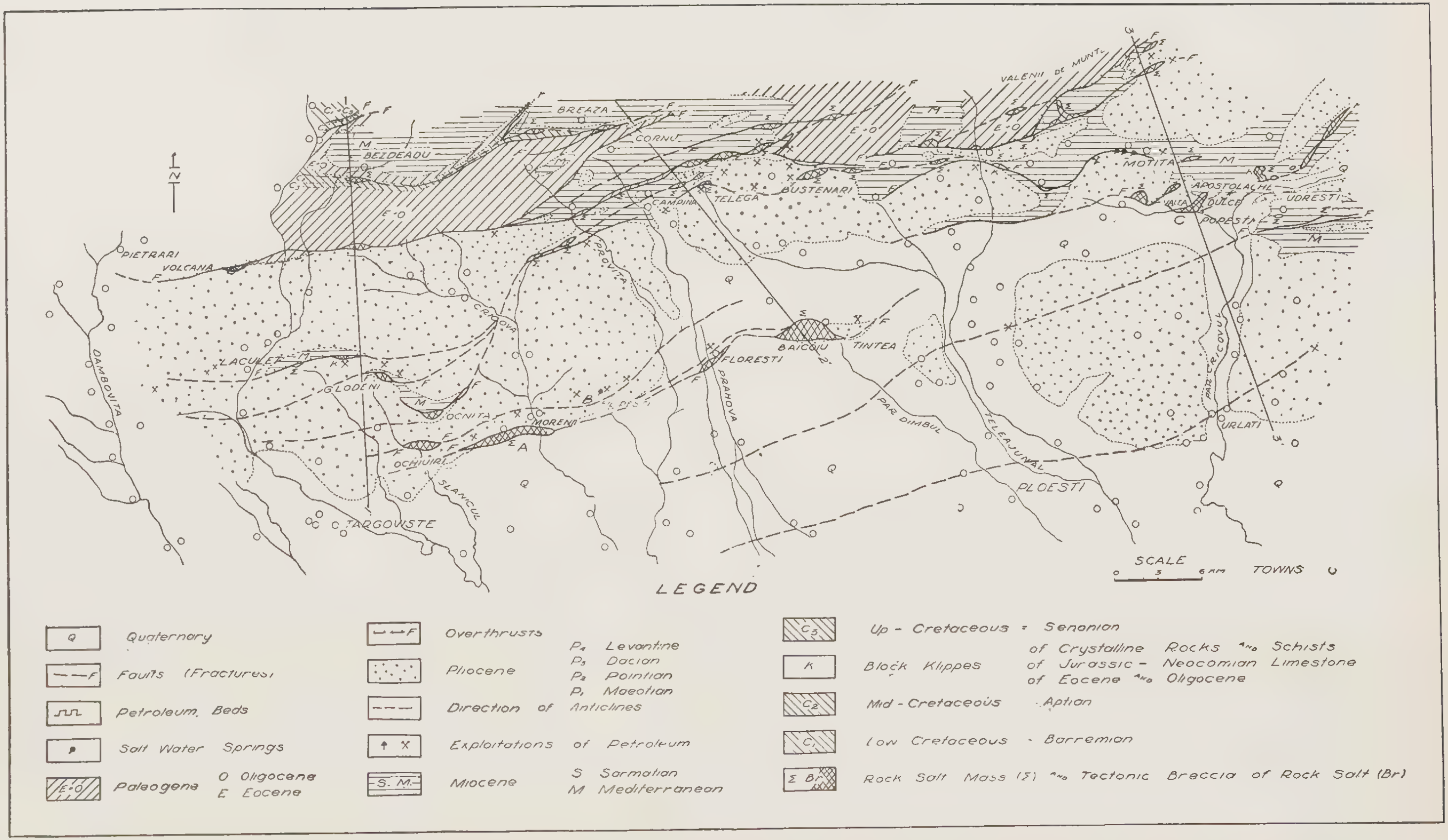
N
PIETRARI
VOLCANA
DAMBOVITA
LACULET
GLODENI
OCNITA
OCHIURI
TARGOVISTE
SLANICUL
CRICOVA
MORENI
PROVITA
BEZDEADU
BREAZA
CORNU
CAMPINA
TELEGA
BUSTENARI
FLORESTI
PRAHOVA
BAICOIU
TINTEA
PAR. DIMBUL
TELEAJUNAL
PLOESTI
VALENII DE MUNTE
MOTITA
APOSTOLACHE
VALEA DULCE
PODENII
UDRESTI
PAR. CRICOVUL
URLATI
E-O
M
F
Q
SCALE
0 3 6 KM
TOWNS
LEGEND
Quaternary
Faults (Fractures)
Petroleum Beds
Salt Water Springs
Paleogene O Oligocene E Eocene
Overthrusts
Pliocene P_4 Levantine P_3 Dacian P_2 Pontian P_1 Maeotian
Direction of Anticlines
Exploitations of Petroleum
Miocene S Sarmatian M Mediterranean
Up - Cretaceous - Senonian
Block Klippes of Crystalline Rocks and Schists of Jurassic - Neocomian Limestone of Eocene and Oligocene
Mid - Cretaceous - Aptian
Low Cretaceous - Barremian
Rock Salt Mass (Σ) and Tectonic Breccia of Rock Salt (Br)

FIG. 3.—Geologic map of the south side of the southern Sub-Carpathians, with special regard to the distribution of the rock salt domes

(For location see Plate 1)

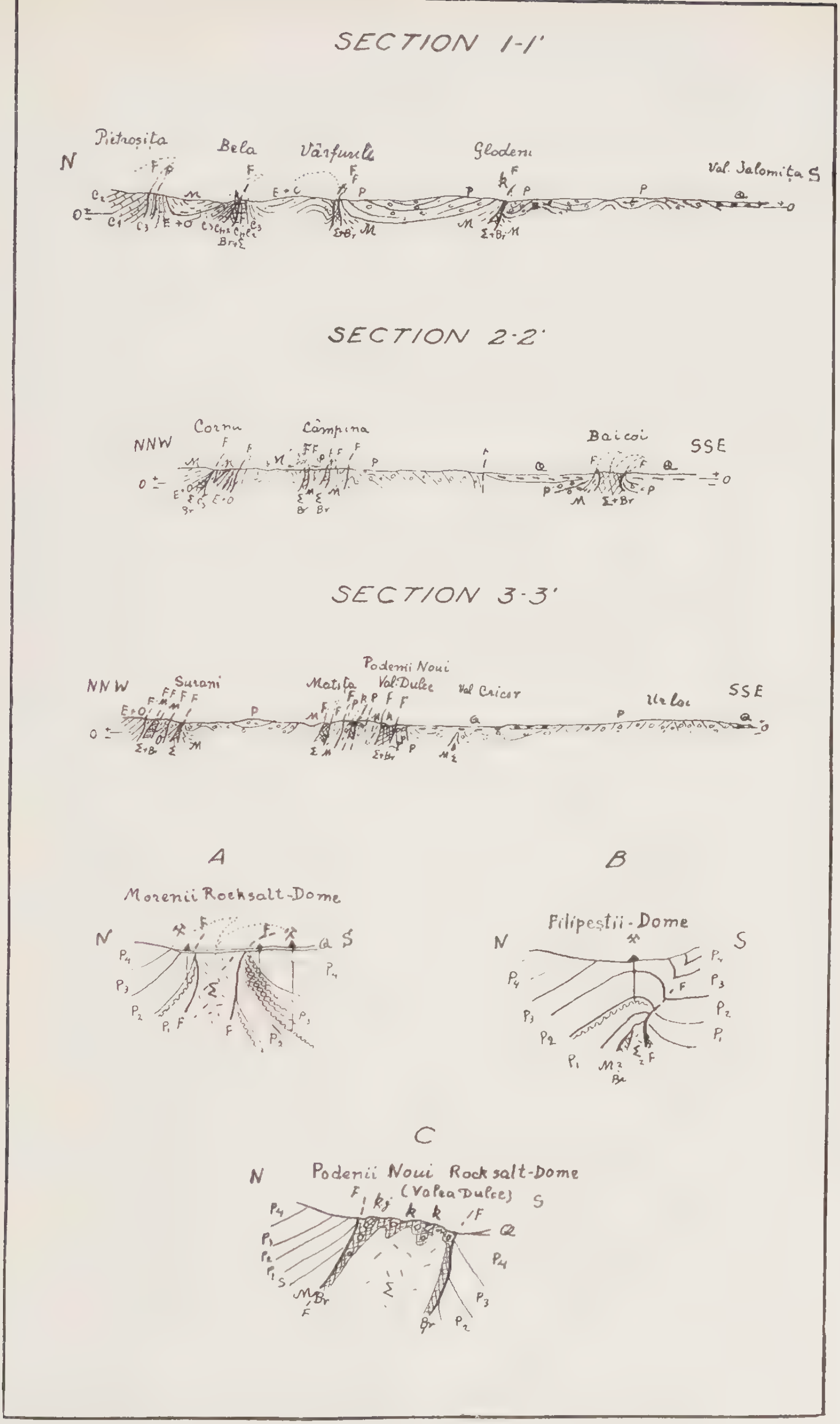

FIG. 4.—Geologic cross-sections of the area shown in Figure 3

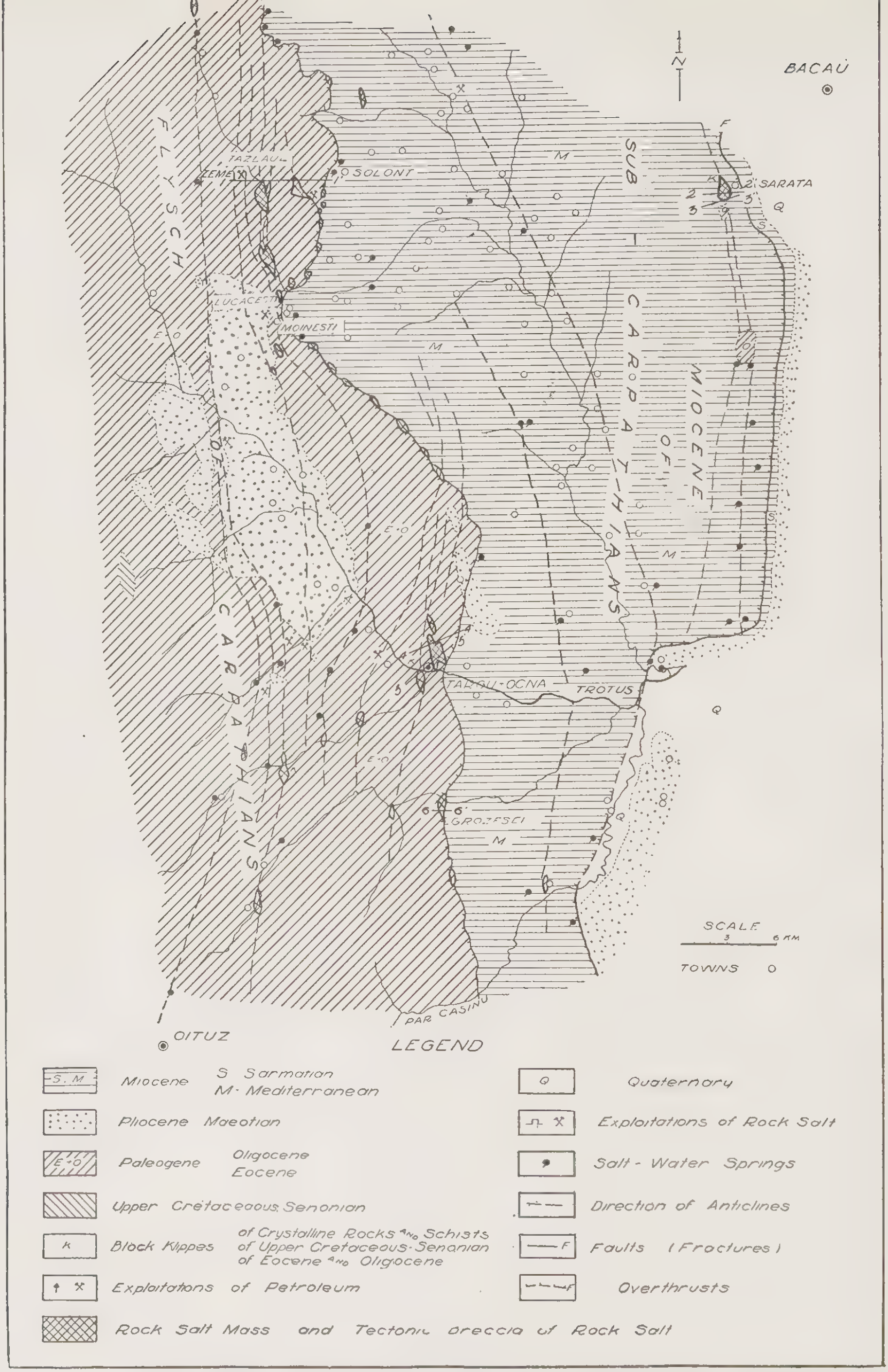

FIG. 5.—Geologic map of the east side of the eastern Carpathians and Sub-Carpathians, with special regard to the distribution of the rock salt domes. For location see Plate 1.

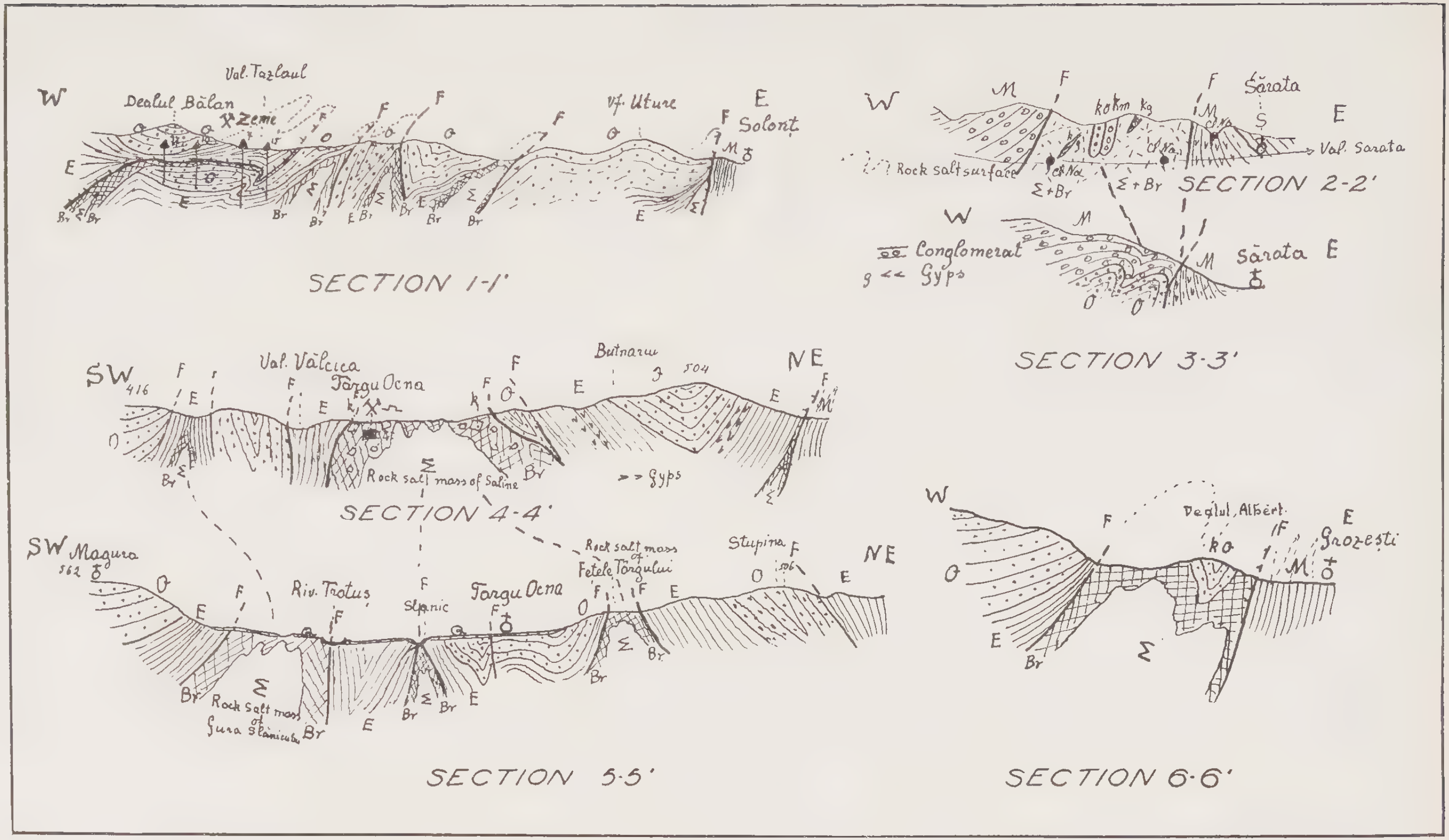

FIG. 6.—Geologic cross-sections of the area shown in Figure 5

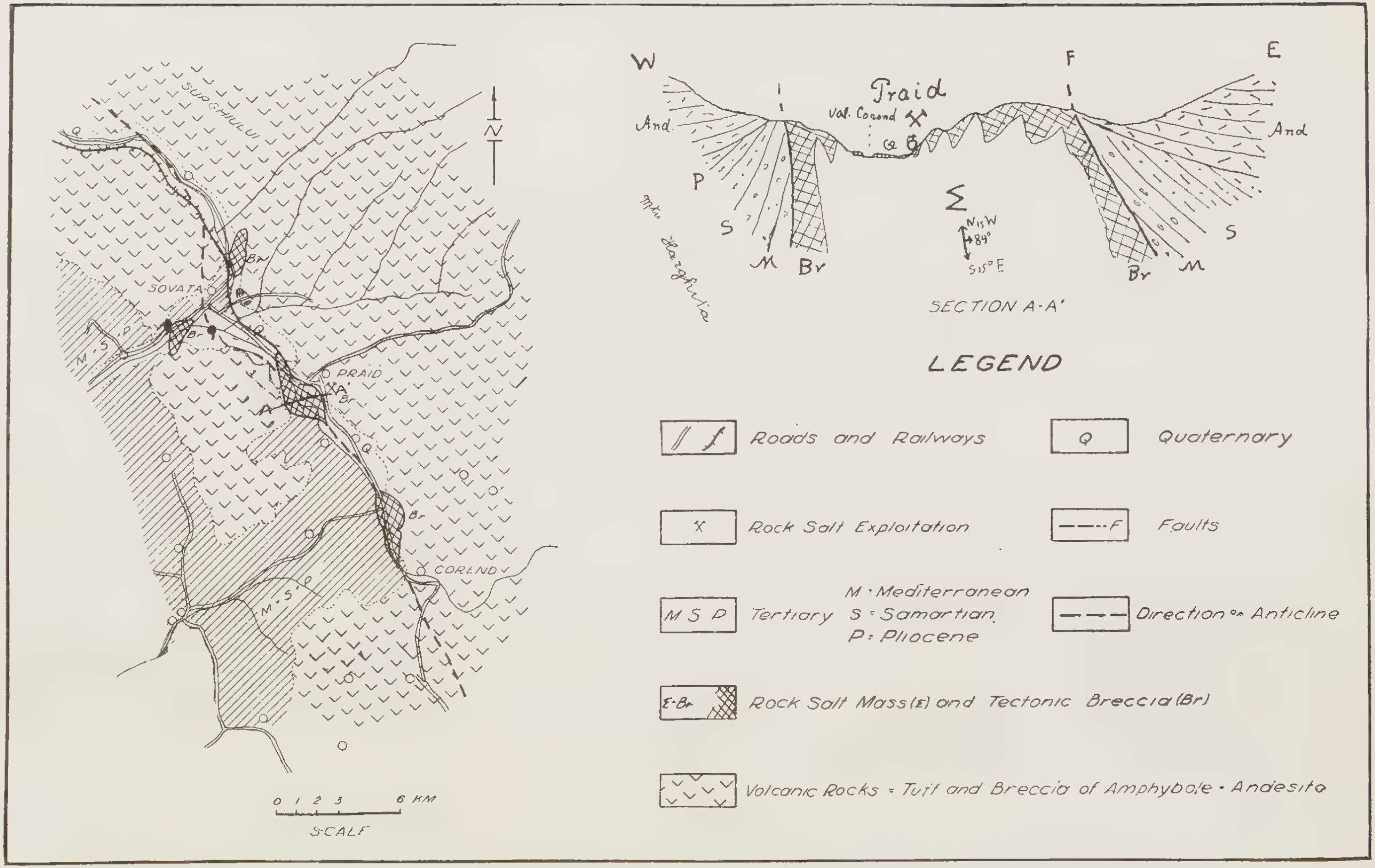

FIG. 7.—Geologic map of the eastern border of the Transylvanian basin, with special regard to the distribution of rock salt domes

(For location see Plate 1)

mountains ("Muntii Apuseni"), on the fault that separates these crystallines from the Mio-Pliocene of the depression, there is a strong salt spring.

The map of the salt deposits and salt spring (Plate 1) shows that in Bucovina they are scattered over the whole zone of the Paleogene Flysch, from the border of the crystallines to the sub-Carpathians, while in Moldavia they are commonly grouped together near the outer border of the zone of Paleogene Flysch and the inner border of the Miocene of the eastern sub-Carpathians.

The southern curve of the Carpathians may be considered as beginning at the river Trotus and the town of Targu-Ocna, where the strike is N. 15°–20° E., continuing to Ochiuri-Ocnita, in the district of Dambovita, where the strata strike is N. 70°–75° E. Outside the Carpathians the salt masses as well as the salt springs are not only more numerous, but also scattered over the entire breadth of the sub-Carpathians, from their border toward the plain, beyond the inner border of the terminations of the Paleogene Flysch, up to the fractured border of the Lower Cretaceous zone of the high Carpathians. In the vicinity of the same curve, and especially in the southern part of Moldavia, the salt domes and springs appear in the interior of the Paleogene Flysch zone of the Carpathians up to the high crest of the mountains. They are found in the valley of Slanicul Moldovei, and in the valley of Oituz, even beyond this crest (at Poiana Sarata and Oituz), on the Transylvanian side of the mountains (Plate 1 and Figs. 5 and 6).

It should be remembered, also, that opposite this curve of the Carpathians there are the salt and alkaline lakes of the Rumanian plain, scattered over the whole zone between the rivers Ramnicul Sarat, Ialomita, and Danube (at Braila), the lakes being supplied by springs containing salt and magnesia.

In the Transylvanian basin the salt domes appear along the anticlinal crests in the direction of the Miocene (north-northwest—south-southeast), the salt masses being much more numerous along the fractures that accompany the borders of this depression than in the interior of it. In Oltenia these occurrences are all grouped together in the narrow strip of Cretaceous-Paleogene-Miocene, in the vicinity of the fault of the crystalline outlier of the Getic Mountains.

In Maramuresh they are grouped in the Paleogene-Miocene in the northeastern end of the Panonic depression, which touches here on the border of the crystallines of the northeastern Carpathians.

The broad zones separating the salt domes and springs in the interior of the old Carpathians from those on the exterior generally have a foundation formed of crystalline schists, deeply metamorphosed, and old eruptive rocks as well as the spots of Paleozoic-Mesozoic, more or less metamorphosed and closely connected tectonically with the crystallines.

From these statements it might be deduced that the salt domes of the Carpathian regions are connected with the zones in which the older geologic formations have not suffered such metamorphism. Also, study of the grouping of these salt domes in the different structural units of the Carpathian zones show that they are connected with the zones of more recent geosynclinal depression, namely, of the geosynclines produced since the Upper Cretaceous. The occurrences of salt masses and springs are much more numerous as these increase in proportion to the depth of the troughs.

RELATIONS OF THE SALT DOMES TO THE FOLDS AND FRACTURE LINES OF THE CARPATHIAN MOUNTAINS

All the salt masses and springs of the Carpathians are confined to the cores of the anticlines, regardless of the age of the geologic formations constituting their flanks or their cores. In no case do these domes or springs appear in synclines. Where the salt masses come to the surface in the cores of the anticlines, their crests are fractured, and very frequently, besides these fractures, the flank that is on the inner side of the corresponding Carpathian zone overlaps the outer one, which, in this case, is sunken and folded over the adjoining syncline (Figs. 3 and 4). In the sub-Carpathians as well as in the Transylvanian basin, but especially in the zone of the Cretaceous-Paleogene Flysch of the eastern Carpathians and the southern sub-Carpathians, the anticlinal lines are in most cases highly developed in the whole region. The salt masses are aligned along them in garlands piercing their crests from place to place. In the points where the salt masses did not reach the surface, salt springs are found on the apex of the anticlines (Figs. 3, 4, and 5). The great development of longitudinal faults throughout the Carpathians has facilitated the intrusion of the salt. This is the case with the great longitudinal fault on the outer border of the Flysch of the eastern Carpathians where the Cretaceous-Paleogene Flysch overlaps the sub-Carpathians and where the most numerous salt domes appear. The same is true in the fractured anticlines in which the Cretaceous-Paleogene Flysch of the eastern Carpathians ends in the southern sub-Carpathians. Other examples are the great flexure on the outer border of the eastern and northeastern sub-Carpathians, and those on the ends of the anticlines of the Mio-Pliocene in the southern sub-Carpathians toward the Rumanian plain and the Getic depression of Oltenia (Figs. 3–6). Finally, faults also delimit the depression of the Transylvanian basin (Fig. 7), which contains many salt domes.

TECTONICS OF SALT-DOME INTRUSION

Irrespective of the zone in which they appear, whether the Carpathians, sub-Carpathians, the Transylvanian basin, or the prolongation of the Panonic depression in Maramuresh, the salt masses appear to be genetically identical. The salt everywhere appears in the form of great lenticular masses more or less elongated along the major anticlinal axes and generally cutting the anticline obliquely in vertical section.

Around the salt mass there is generally a tectonic breccia, formed from fragments of different rocks, whose size varies from fine clay up to large blocks, rounded or angular with dimensions from some centimeters up to several meters, and sometimes (in Valea Dulce, at Podenii Noi) even some hundreds of meters (Figs. 3 and 4). The formations that remain unbrecciated on the flanks of the anticline sometimes present incipient stages of brecciation. In the great majority of cases these strata have been thrust backward and upward. Their margins are thinned upward along the gliding surface that separates them either directly from the salt mass, or from its surrounding breccia, when this is present. Each component of the domes will now be described.

The salt.—The salt is chemically very pure and is all crystalline, generally with a granular structure, and rather fine-grained. Only in the sheared zones with brecciation and recrystallization does the salt appear impure, harder, and in large cubic crystals, which are sometimes very large. Foreign elements are gypsum and fragments of clay folded into the salt.

The salt masses are always banded with darker stripes because the salt is a stratified deposit. The thick strata are white; the thin strata (2–3 cm. thick) are dark in color but pure in composition, the darker coloration being due possibly to some inclusions of a chemical nature[1] (Fig. 8). The presence of these bands furnishes a means of knowing the intimate tectonic structure of the mass. The countless synclinal and anticlinal folds (Fig. 9) which show intense squeezing and fracturing, especially in the synclines, indicate the powerful compression that the salt masses underwent during their intrusion. The abundant breccia that is developed around the salt masses is obvious proof of the enormous mechanical force that was

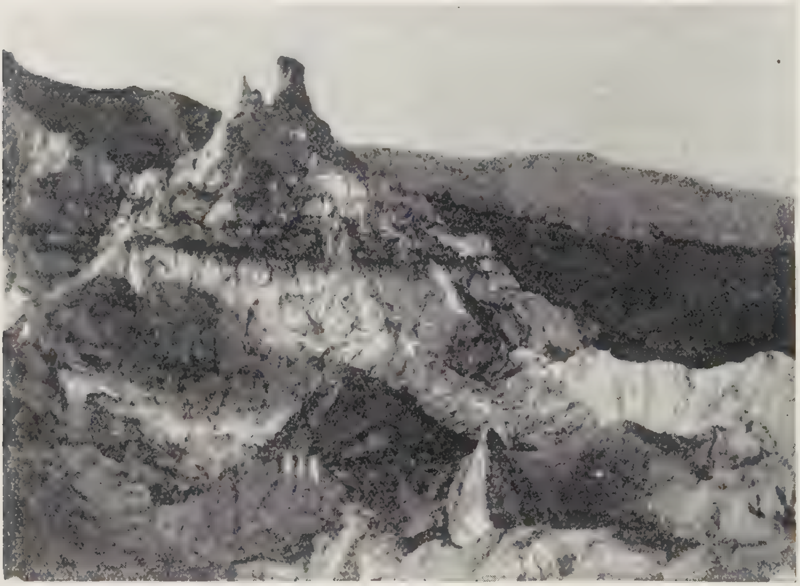

FIG. 8.—Variegations and phenomena of dissolution on the surface of the rock salt outcrop at "Baia Baciului," Slănic, Prahova (Muntenia).

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[1] Dark color bands in American salt domes are caused by anhydrite crystals.—EDITOR.

exerted against the rocks of the cores and the arches of the anticlines in order to pierce them on their way upward. This force caused the characteristic folded structure.

The flanks of the domes are usually curved and almost vertical. Downward enlargement is asymmetrical with the straight side away from the direction of thrust. The crest of the salt mass or the crests, if these are multiple (Baicoi-Tintea, Bana, Cacica, etc.), present different aspects according both to the section of the mass considered and to the shape of the anticlinal fold.

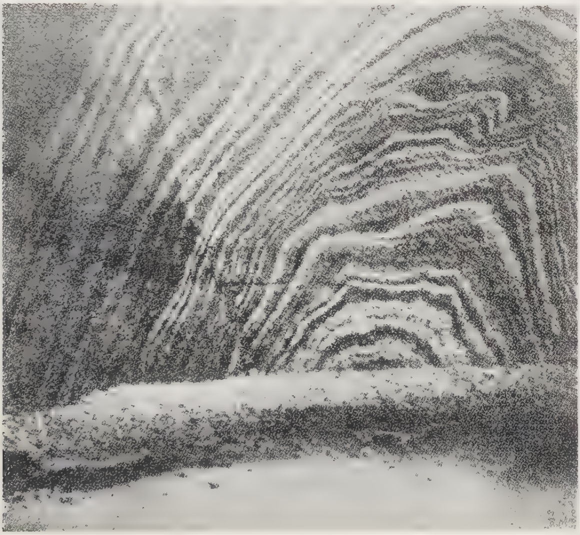

FIG. 9.—Anticlinal fold made conspicuous through variegations in a gallery in the "Ocnele Mari," Valcea (Oltenia) salt dome.

Domes that reached the surface through a complete fracturing of the anticlinal crest crop out in circular form. Where the anticline contains local domal nodes, as is generally the case of the salt masses of Transylvania (Uioara, Sovata, Praid, etc.), the salt core enlarges downward a short distance. The outline of other salt cores is oval (Gura Slanicului, Moldova, Ocnita, etc.). Still others have sinuous, pod-shaped, or crescentic outlines, as in the domes of the Carpathians or the sub-Carpathians (Targu-Ocna, Moreni, Ochiuri, Slanic-

Prahova, Ocnele Mari Valcea, Martiia, Apostolache, Podenii Noi, etc.). These are on long anticlinal lines whose crests are more or less inclined and sometimes recumbent (Figs. 3–7).

Outcrops of salt show characteristic signs of erosion modeled by running water (Figs. 8, 10, and 11). They show concave surfaces, large funnel shaped sink holes, and salt lakes (Telega, Targu-Ocna, Gura Slanicului, Sovata, Slanic, etc.). Sometimes, because the bottom is covered with fine deposits of clay, the lakes contain fresh water (Baicoi, Campina, etc.).

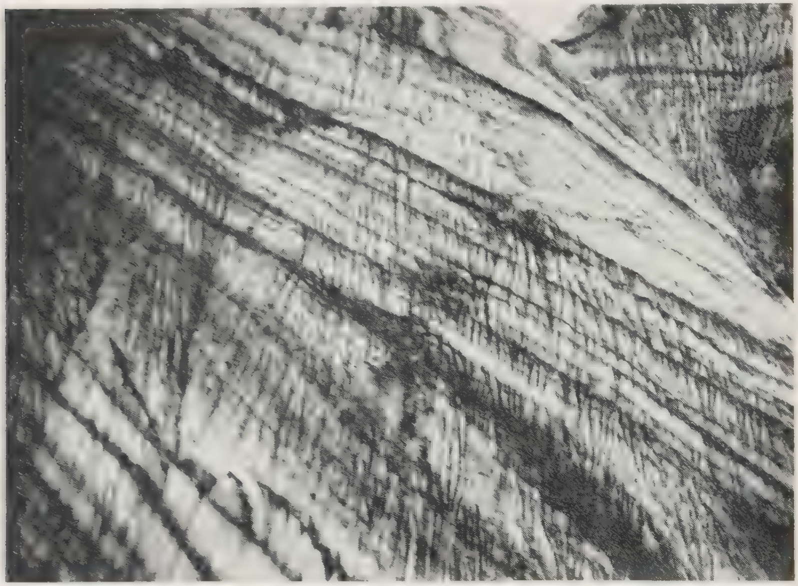

FIG. 10.—View of the rock salt mass of Slănic, Prahova that appears at "Baia Baciului." A recumbent anticlinal fold is to be observed.

Superficial enlargement of the edges of the salt cores, as determined by vertical sections, is due to the plasticity of the salt, which causes flowage on release from the pressure of the rocks on the flanks of the anticline. Salt cores that do not reach the surface have a lenticular form, with a sharp crest, or are irregularly folded. The crests of some domes after having pierced vertically a part of the rocks curve laterally and intrude horizontally between the upper strata for greater or less distances (Dej, Transylvania). Considered as a whole, the salt core constitutes an entire and compact unit, like a great lenticular kernel, intensely folded and refolded.

There are cases in which the salt core has two peaks, separated by a strongly compressed syncline of sedimentary rocks (Baicoi-Tintea). This syncline is sometimes completely brecciated (Cacica-Bucovina), the two peaks being in this case separated by a large zone of breccia. In other cases, through squeezing and flowage, the breccia has been completely obliterated, the peaks being separated by only a thin zone of a harder salt, with larger and less pure crystals, containing rock inclusions that are more numerous at the edges of the core (Slanic-Prahova, Ocnele Mari-Valcea, etc.).

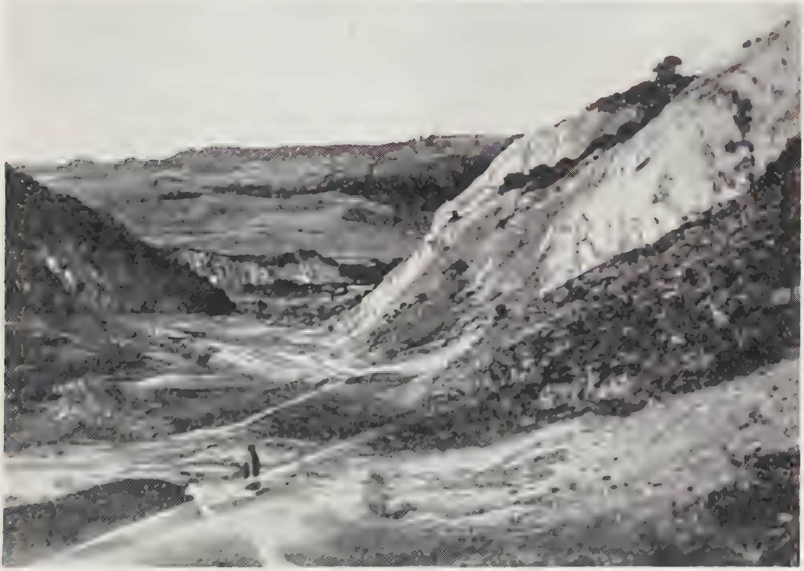

FIG. 11.—The rock salt mass of Praid, Transylvania, crossed by the valley "Corond"; the salt is white, the tectonic breccia dark.

All the fossil remains found thus far in the rock salt come only from those inclusions which were torn off in the synclinal parts of the intrusion and afterward squeezed and laminated. Consequently, they do not belong to the salt, but to the sedimentary formations surrounding it, through which the salt mass has penetrated. The breccia separating the crests of the salt mass of Cacia (Bucovina) consists only of Oligocene and Eocene rocks. The very laminated breccia in the salt mass of Slanic-Prahova is formed of Eocene and Mediterranean rocks. The rocks separating the crests of the Baicoi-Tintea and Bana (Prahova) salt domes belong to the Upper Pliocene (Docian).

The Breccia around the salt cores.—This breccia is a tectonic formation, and was produced during the intrusion of the salt mass by the fracturing of all the formations through which it pierced. The greater part of the breccia is derived from the rocks of the uppermost formations. Around the salt cores of the Cretaceous-Paleogene Flysch of the eastern Carpathians the breccia contains fragments of the Senonian, Eocene, and Oligocene. Eocene-Oligocene fragments predominate in the cores that pierced to the surface through the whole series of Flysch (Targu-Ocna, Stanesti-Solont, Grozesti, etc.). Fragments of Eocene rocks only occur in the masses that did not pierce through the whole series (Gura Slanicului, Slanic Sat, Tazlaul Sarat, etc.).

In the sub-Carpathians, where the known geological formations embrace the entire Tertiary, the breccia usually consists of Paleogene-Miocene rocks. One example is Sarata, near Bacau, where there also is a great *Klippe* of Paleogene; others are found in the southern sub-Carpathians (Slanic-Prahova, Gorganu, Valea Bisericii at Poiana de Variblau, etc.), in the region of the last anticlines in which Paleogene Flysch is exposed, Figs. 3–6).

Around the cores that have stopped in the Miocene of the Transylvanian basin, as well as around those on the outer border of the southern sub-Carpathians and in the Getic depression, the tectonic breccia consists either of Miocene rocks only (Transylvania and the Getic depression) or of Miocene and Pliocene rocks. A number of *Klippen* of Oligocene occur on the border toward the plain of the southern sub-Carpathians (Floresti, Matita, Apostolache, etc.), and on the eastern border of the Transylvanian basin (Sovata, Corond, etc.).

In most of the domes in the Pliocene of the southern sub-Carpathians, either breccia is absent (Ochiuri, Gura Ocnitei-Moreni-Bana, etc.), in which case it was left behind when the salt mass entered the Pliocene, or the breccia is represented only by some rather small masses that could have been broken off and carried up by the salt mass from the breccia that remained at a depth (Baicoi-Tintea, Floresti, etc.). The scarcity of breccia is attributed to the plasticity of Pliocene rocks, which consist of loosely compacted sands and clays.

Fragments of formations older than the Tertiary in the southern sub-Carpathians are confined to the breccia around the salt masses in the vicinity of the marginal fault of the southern Carpathians and in the zone of the terminal anticlines of the Carpathian Flysch, ending in the sub-Carpathians. Thus, at Bertea (Prahova) the salt springs issue from the Aptian, which is brecciated by a salt dome[1] that did not reach the surface. In the valley of Saratila, at Breaza (Prahova), the breccia contains Paleogene-Miocene as well as Senonian rocks. In the core of the anticline of Bela-Bezdeadu (Dambovita), in which a salt core occurs, rocks belonging to the Aptian, Senonian, Eocene, Oligocene, and Miocene appear in the breccia and on the flank of the anticline. Some enormous blocks of Jurassic limestone have been found in some cases, as at the Vf. Ursului (Figs. 3 and 4).

Considered from the point of view of the resistance of the rocks from which the breccia was formed, the marls and shales are generally finely ground, the conglomerates are completely disassembled by breakage, and the sandstones and limestones are generally broken to pieces, their fragments large or small usually being angular. The rounded pieces of quartz in the conglomerates, through rubbing with finer fragments, are sometimes perfectly polished. Some geologists confuse this polish with the gloss of desert varnish.

Besides these constituents, whose origin may be very easily determined by comparison with the rocks of the surrounding formations, fragments of unknown formations that are wholly foreign to the region and cannot be attributed to any of its known geological formations are found.

In the tectonic breccia of all the salt masses that appear in the Carpathian Flysch and in the Miocene of the eastern sub-Carpathians, besides large or small fragments of eruptive rocks and crystalline schists that may be compared with those in the distant areas of crystalline in the old Carpathians, there are also found numerous fragments, generally angular, usually small but in places enormous, of eruptive rocks and green crystalline schists, of the types that form the remnants of the old Variscian chains of the northern Dobrodja. These fragments can be derived only from the old Variscian foundation of the geosyncline of the Carpathian Flysch and of the eastern sub-Carpathians, a basement formed by the prolongation of the northern Dobrodja chains which sank during the formation of this geosyncline (Poiana Sarata, Grozesti, Slanic Sat, Targu-Ocna, Tazlaul Sarat, Sarata-Bacau, etc.).

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[1] "The salt itself is not responsible for the brecciation. It is due to structural forces, which also squeezed the salt upward."—Bloesch.

In the same manner in the southern sub-Carpathians, besides the fragments that came from the surrounding formations (Cretaceous, Paleogene, Miocene) and formations older but still of the Carpathian type, as fragments of crystalline schists and eruptive granitic rocks of the Carpathian type and Mesozoic (Jurassic) limestones closely connected with this crystalline in the southern Carpathians, there also appear in the salt-dome breccia a few fragments of rocks wholly foreign to the Carpathian region. Their proportion in the breccia is proportionally greater, the nearer the salt mass is to the plain. For instance, in the salt-dome breccia of Valea Dulce, near Podenii noui (Prahova), besides the large and small angular fragments of mica schist and (eruptive) gneiss of Cozia, and Jurassic fossiliferous limestone of pure Carpathian type, there also appear exotic fragments of a black quartzose sandstone (Carboniferous?), a red porphyry with great crystals of feldspar, and blocks of limestone with *Nerinea*, one of which, now completely exploited, was over 700 cubic meters in size. These rocks are generally known only in the Dobrodja and the Pro-Balkans, not in the Carpathians, and they were surely derived from the Pro-Balkan foundations of the Rumanian plain and of the southern sub-Carpathians (Figs. 3 and 4).

All these fragments of the breccia form a strongly compacted mass, well cemented by the salt,[1] sometimes also by gypsum. Generally the salt of the cement becomes much more abundant in the vicinity of the salt mass, where the breccia is finer and is more strongly compressed than toward its exterior. Gypsum very often re-cements the sandstones and the broken conglomerates; in places it even forms lenses of fibrous gypsum or kidney-shaped crystalline masses.

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[1] At Targu Ocna, in the rock-salt dome, breccia of *Valea Larga* were found, also some blocks of potassic salt (carnallite and sylvinite).

Where the breccia appears at the surface it may be very easily recognized from distinctive characteristics: salt springs or strong saline efflorescences; the greasy aspect and knotty texture of the soil (Fig. 12); the presence of fragments of several kinds of more resistant rocks heaped up on the surface; the finer materials of the breccia having been washed away by the rains; and, finally, the complete lack of vegetation, or, if any exists, the presence of plants which grow on salty soils.

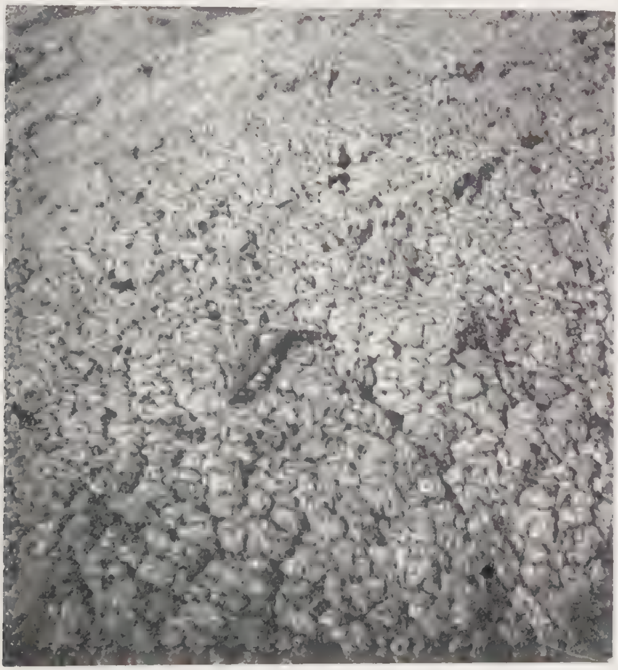

FIG. 12.—Knotty clay-breccia in contact with the surface of the rock salt mass of Sovata, Transylvania.

The rocks in the flanks and on the anticlinal arches that remain unbrecciated by the salt cores.—The visible formations constituting the flanks and the crests of the anticlines which are intruded by the salt masses belong generally to the Pliocene, Miocene, and Paleogene, less frequently to the Upper and Lower Cretaceous. The formations vary according to the region in which the salt domes appear.

When the anticlinal arch is completely brecciated, the trace of the outcrop of strata that remain unbrecciated is lens-shaped. The dips are different on either flank, being less steep on the upper flank and greater on the inverted one. In the neighborhood of the breccia, or, when this is missing, near the salt mass, the strata on both sides are turned upward, squeezed, and reduced in thickness through lamination. Near the surface where the salt overflows they are bent outward, forming fan-shaped anticlines. These overturnings are much more pronounced on the inverted flank, which is generally depressed and hence often overlapped (Figs. 3–7).

Owing to the numerous wells in search of oil that have been drilled in the vicinity of the salt domes—the formations of the petroleum deposits in Rumania having close genetic connections with the salt domes—it has been established that the salt is diffused in the strata of the flanks of the anticlines for great distances around the salt mass when the fractured borders of these strata come in direct contact with the salt mass or its breccia. This is shown chiefly through the presence of salt water in the porous rocks of the flanks.

Toward the extremities of the salt lens, where the salt core disappears, the strata of the two flanks unite to form the arch of the anticline. Here the overlying strata are curved in the form of a broad arch and those of the core are folded together like a sharp wedge with the edge upward. The underlying strata are more or less thinned through squeezing and lamination (the "diapir" folds of Mrazec). According to the position of this wedge, whether vertical or oblique, these are classed by Mrazec as upright, oblique, or recumbent diapirs (with a piercing core). The last two in most cases are fractured and overturned.

An essential characteristic of these diapir folds is that, from a geographical point of view, the strata of the anticlinal arch are generally passive, the core alone being active in causing the intrusion. This may be seen in the study of the arches that were not completely pierced. The arch takes the form of an elongated dome, with the core more or less brecciated. In this case the extremities of the dome present the same structure as in the case of complete piercing. But the dome, judged from the point of view of symmetry, may present two different cases. The first is when the salt mass rose vertically (and in this case the arch is symmetrical), but the strata of the flanks are laminated through squeezing, until they are completely torn from those of the arch. This is the case in the anticlines of Ceptura and Arbanas, in the southern sub-Carpathians. The second case is when the salt mass does not rise on a vertical line, but obliquely, and then the arch and the flanks are naturally asymmetrical, the inverted one being more inclined, distended, and sometimes drawn out to complete rupture. Examples are known at Filipestii de Padure and generally in the whole Transylvanian basin (Figs. 3–7).

AGE OF THE SALT OF THE CARPATHIANS

The first person who tried to establish the age of the rock salt of the Carpathian deposits was the Viennese scholar, the geologist Eduard Suess (1).[1] He correlated it with the *Schlier* (the base of the second Mediterranean—the base of the Helvetian) of the Miocenic outer Alpinic basin of Vienna. The great authority of Suess caused this age to be accepted without much discussion by all the geologists of the countries bordering the Carpathians—Rumanians, Austrians, Polanders, and Hungarians.

Later on, after the discovery of some Tortonian fossils in the breccia of the salt dome at Wieliczka and at Bochnia (2, 3, 4), the Galician geologists, and, after them, Haug (5), considered the salt of the sub-Carpathians as representing a lagunal facies of the Tortonian.

The Hungarian geologists, Posepny, but chiefly Koch (6) and H. Böckh (7, 8), who occupied themselves more intimately with the stratigraphy of the Transylvanian basin, considered the salt as intercalated in the marls that form the base of the bathyal facies of the Helvetian (the strata of Mezoseg), marls resting directly on the lower and thicker beds of eruptive tuff (Dacitic).

Further studies on the Mediterranean of the sub-Carpathians gave rise to numerous discussions among the Rumanian geologists about the age of the rock-salt masses. Mrazec and Teisseyre (9, 10, 11) originally assumed an Eocene-Oligocene age for the salt of the Carpathians, and a Mediterranean (Helvetian) age for the salt of the sub-Carpathians. Later on, Mrazec (15) and Voitesti (16) brought it down to the base of the first Mediterranean (Burdigalian), and, although this opinion was contended (Sava Athanasiu [13]), the majority of the Rumanian geologists (Murgoci [12], Macovei [14], Merutiu [17], etc.) accept the same age today.

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[1] The numbers here and elsewhere refer to the bibliography at the end.

The author (18–24) of this paper, from 1911 to the present, has drawn the attention of geologists several times to the mistake that is being made in considering the salt as Miocene. Excluding the great number of salt masses appearing in the interior of the Carpathians, at enormous distances from their outer border, where the Cretaceous-Paleogene Flysch of the Carpathians comes into contact with the Miocene, the salt masses that appear in the Miocene and the Pliocene of the sub-Carpathians pierce not only through the whole series of Mediterranean and Pliocene strata, but even extend through the Eocene and Oligocene formations which always appear as large or small *Klippe* (overthrust) areas, generally brought up from a depth by the rock-salt masses. Thus, the mass of Sarata, near Bacau, on the exterior border of the Miocene of the eastern sub-Carpathians (Figs. 5 and 6), appears beneath a large *Klippe* of Oligocene, which, together with the whole overlying series of Mediterranean strata, is completely brecciated, in the zone where the salt mass is present (Voitesti [19]). With a marginal position in the sub-Carpathians the salt masses between Vizantea and Soveja (district of Putna) also appear beneath the great *Klippe*[1] of Paleogene of the peak Rachitasul. In the southern sub-Carpathians the most numerous salt masses are in the zone of the *Klippen* of Eocene and Oligocene that are the western extension of the anticlines of the Flysch.

Klippen of Paleogene rocks are not confined to this terminal anticlinal zone. They also occur on the Mio-Pliocenic border, toward the plain of the sub-Carpathians, for instance, in the salt domes of Scaiosi, Opariti, Sarari, Matita, Apostolache, Udresti (25), Gura Draganesei, etc. Moreover, all the salt domes that appear along the fracture zone of the exterior border of the eastern Carpathians (along which zone the Cretaceous-Paleogene Flysch overlaps the Mediterranean of the sub-Carpathians) have a tectonic breccia formed exclusively of fragments of Eocene-Oligocene rocks (Cacica, Lucacesti, Moinesti, Targu-Ocna, etc.), or else largely of Eocene-Oligocene rocks with very few fragments of Mediterranean rocks in the upper part of the breccia (Calu, Stanesti, Valea cu Arini, Poduri, Grozesti, etc. [Plate 1; Figs. 5, 6, and 13]). Furthermore, along this marginal fault there are numerous cases in which we find the salt masses hidden partly under the border of the Paleogene Flysch; partly under the rocks of the neighboring Mediterranean, as, for instance, in the border region of the Flysch, between Targu-Ocna and Solont (district of Bacau [see Figs. 5 and 6]), and in the region of the southern curve of the Carpathians (in the district of Ramnicul Sarat), in which regions the folds of the Flysch are cut off obliquely by this marginal fault.

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[1] *Klippen* are outliers of an overthrust (Chief Mountain Montana, is an example) in contrast with a *Nappe* (*Decke*) which is the overthrust mass itself.—EDITOR.

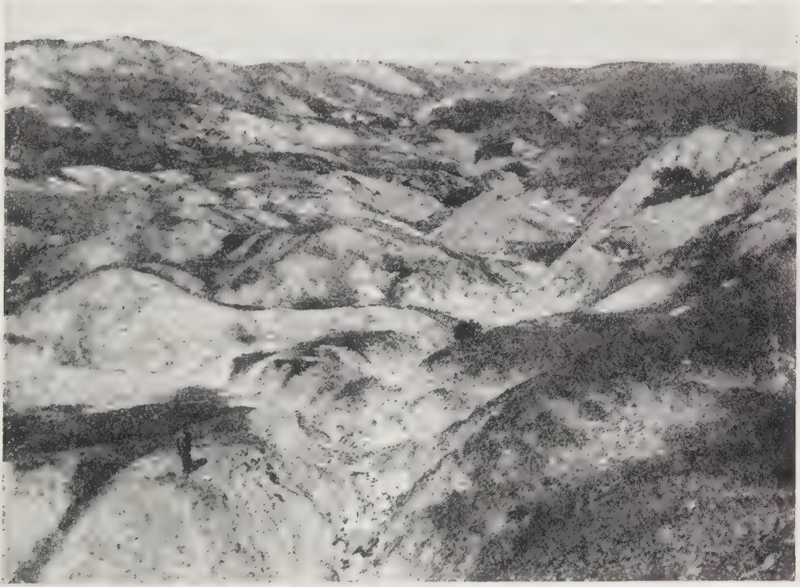

FIG. 13.—The tectonic breccia of the "Fetele Targului" salt plug, near Târgu-Ocna, Moldova, formed of Eocene and Oligocene rocks with inclusions of Cretaceous limestone and of crystalline schists. Note the funnel-shaped aspect of its surface.

If to these examples the salt domes of Bertea-Vulpea, Breaza, and Bezdeadu-Bela, in the anticlinal flanks and tectonic breccia of which the Cretaceous (Senonian and Aptian) formations as well as the Paleogene occur, are added, and if the fact is remembered that wherever the salt masses appear they present the same tectonic and physico-chemical conditions, the conclusion is logical that the rock-salt masses of the Rumanian Carpathians and sub-Carpathians cannot, in any case, be considered Miocenic—a conclusion also reached by some foreign geologists who studied conditions in the field (E. H. Cunningham Craig [26]).

The salt domes of Transylvania, which have been studied by the author (Ocna Sibiului, Uioara, Turda, Cojocna, Dej, Sovata, Praid, and Corond), show absolutely identical tectonic and physico-chemical conditions. There surrounding breccia, sometimes enormously developed (Turda, Sovata, Praid, Corond), is formed only of fragments of rocks of the Mediterranean, in which the salt mass is arrested, and fragments of crystalline schists and old eruptive rocks (Turda, Sovata) sometimes very strongly represented (Praid, Conond). All these fragments may come from the conglomerates at the base of the Mediterranean. Up to the present, fragments have not been found in these breccias that can be assigned with absolute certainty to formations older than the Mediterranean. One fact, however, remains well established: that in the Transylvanian basin also the salt masses pierce the whole series of strata of the Miocene, from the conglomerates at the base to the upper sandstones and marls, and so they, too, cannot be considered as belonging to the Miocene. At Praid, Sovata, and Corond, there are also found in the breccia numerous andesitic fragments (ashes and fragments of rocks) as well as fragments of the aragonitic chemical concretionary deposits of the hot mineral springs that appeared here in connection with the recent volcanic phenomena of Harghita (Fig. 14).

The Tortonian fossils found at Wieliczka and Bochnia in the tectonic breccia of the salt cannot have any stratigraphical importance because the breccia being a tectonic and not a sedimentary formation, in its mass there may be found fossils belonging to all the geological formations that were passed through and brecciated by the salt mass. For instance, in the breccia of the salt domes in the sub-

Carpathians fossils were found which belong to all the geological formations from the Jurassic up to the Upper Pliocene. In the dome of Ocnele Mari (Valcea) there were found in the squeezed synclinal zones of the salt, where the clay breccia had penetrated from the outside, some remains of Oligocene-Miocene plants (carbonized trunks and nuts). In the salt of some of these domes were also found pockets of petroleum that came in the same tectonic way from surrounding petroliferous rocks.

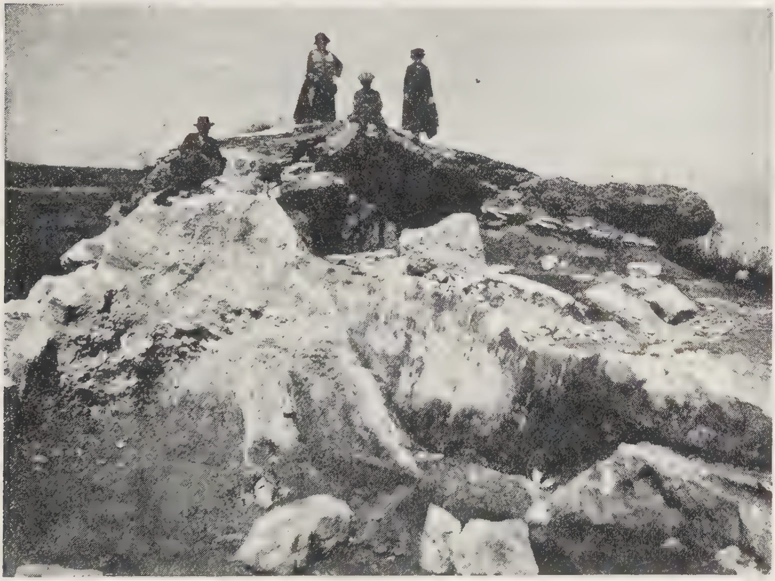

Fig. 14.—Strata of Aragonite torn from their original position and carried upward in the upper part of the breccia of the Corond salt dome, Transylvania.

Moreover, it is the author's opinion that, not only in the Carpathian region of Rumania, but in any other part of the globe where the salt appears in the form of domes, it is a great mistake if the actual tectonic position of those masses is considered as a stratigraphic one. For, the tectonic breccia surrounding them, the development of which is sometimes enormous, shows obviously that the actual position of the domes is entirely a tectonic and not a stratigraphic one.

This mistake has caused the age of these salt domes to be estimated by most geologists from the age of the oldest strata that remain unbrecciated on the flanks of the anticline in which the salt appears. Thus, in the Carpathian regions the salt domes that appear along the same tectonic lines are considered in Poland as Upper Mediterranean, and in Rumania as Lower Mediterranean, or as Upper Oligocene and Eocene, or even Lower Cretaceous, whereas in Hungary they are considered as Middle Mediterranean.

In the other countries besides the Carpathians the same mistake is made. The Austrians consider the salt of the eastern Alps as Triassic, because the salt masses (Hallstadt) stopped in the Triassic. The Germans, on the same basis, considered theirs as Triassic or Permian, according as they are arrested in the Triassic or the Permian. In Northern Africa the salt masses were considered until lately as Cretaceous, and now, after the discovery of the Triassic in the flanks of the dome, they are considered as Triassic.

In summarizing, the following conclusions, based on scientific observations, are considered as definitely established for the salt domes of the Carpathians.

1. From a regional point of view the Carpathian salt domes are connected almost entirely with the zones of more recent tectonic sinking of Cretaceous and Tertiary time and the sedimentary formations of these depressions. Salt is known only in the form of springs in the zones of intense regional metamorphism (Sinca Noua, Varciorova).

2. The salt masses of the Carpathians came from a considerable depth, emerged only in the anticlinal zones and along the great fault lines, piercing and brecciating all the Mesozoic-Tertiary formations of the geosynclines of the Carpathians, sub-Carpathians, and the Transylvanian basin.

3. Judging from their identical tectonic mode of appearance and from their structure and the composition of their salt, identical in all the salt masses of the Carpathian region, they must all be considered as having a common origin, in whatever formation they may appear today.

4. Judging from the enormous development of the tectonic brec-

cia surrounding them, the actual position of the salt masses presents itself as a tectonic and not at all a stratigraphic problem, and this tectonic position does not furnish any scientific conclusion about the age of the salt. The surrounding geological formations, as well as the fossil remains of the salt breccia, and even of the salt mass, cannot have any stratigraphic value in this case in the determination of its age.

5. Considering that in the Carpathians and in the sub-Carpathians the geological formations that are determined with certainty as penetrated by the salt masses are those between the Middle Cretaceous (Aptian) and the uppermost Pliocene (Levantin), it follows that the salt comes from greater depths than the Aptian of the Carpathian geosyncline. The tectonic breccia of some salt domes (Podenii Noui and Bezdeadu-Bela) contains great, even enormous, *Klippen*, of Jurassic limestone, whose presence in those places cannot be explained otherwise than by the same tectonics which were responsible for the salt breccia in which they are found. Those masses must be considered as coming from a depth greater than the Jurassic of the basement of the Carpathians and sub-Carpathians.

From these considerations, and in the absence of safe stratigraphic data on the age of the salt domes of the Carpathians, it seems more practical to mark, on the geological maps, the salt masses, as well as their tectonic breccia, with special colors and symbols. Although the available data merely prove the salt to be older than the Cretaceous-Paleogene Flysch, the intrusion of the salt cores can be more definitely dated. These intrusions took place at the end of the Pliocene and at the beginning of the Quarternary because the youngest strata that are pierced by all the salt masses of the marginal zone of the southern sub-Carpathians (Baicoi-Tintea, Moreni, Matita, Podenii Noui, etc.) belong to the uppermost Pliocene (Levantin). It is also known that these strong movements gave the last organic modeling to the entire Carpathian region. It cannot be affirmed, however, that the salt masses have made their ascent only during those post-Pliocene movements, and it is possible that their ascent may have been subject to great interruptions, and may have been renewed at successive periods of folding.

HYPOTHESES REGARDING THE AGE AND GENESIS OF THE SALT

What, then, is the age of the salt of the Carpathian salt domes? This problem is of great economic importance for Rumania, because of the close tectonic relations of these salt masses with the formation of petroleum deposits.

In order to discuss this difficult problem, one must leave, at least in part, the sphere of positive scientific data and enter that of hypothesis. On this question the opinion of the author is that the salt masses, not only in the Carpathians, but those of the whole surface of the earth, belong to none of the known marine or continental geological formations (20 and 24). The following arguments lead to this opinion.

A study of the mode of appearance of the salt domes on the whole surface of the earth (27, 28, 29, 30, 31, and others) establishes the following generalized characteristics (it should be remembered that only salt domes are considered, not intercalations of impure salt of unimportant extent and thicknesses that are interstratified in lagunal or epi-continental salt-lake formations:[1]

1. On the whole surface of the earth the salt of salt domes appears in the form of enormous, lenticular masses, with very complicated tectonic structure reflecting the enormous dynamic movements that they have undergone. The salt is crystalline and shows an extraordinary chemical purity.

2. Breccia, in some cases of enormous thickness, surrounds almost all the salt masses, and, being a tectonic formation, shows that the salt mass has penetrated the strata to its present position. This gives a certain basis for considering the salt as coming from greater depths, and doubting all determinations of the age of the salt, based only on the knowledge of the age of the rocks in which the salt mass is found. The case of the Carpathian salt masses and those of Northern Africa is instructive enough on that account.

3. The enormous number of the salt masses, presenting absolutely identical structural and chemical characteristics, appearing in various parts of the world in strata of all geological formations, from

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[1] "Some interstratified salt beds are of rather important extension and thickness." —Bloesch.

the Paleozoic to the Quaternary, irrespective of the geological facies of these formations, forces the admission of an absolute independence of the salt masses from all those formations, and consequently their genesis cannot be connected with any of the geological formations in which they appear.

4. Finally, the enormous quantity of pure crystalline salt that is found in thicknesses of hundreds and even thousands of cubic meters in every salt mass; the great number of these masses in the world and in some regions (Carpathians, Germany, Isthmus of Tehuantepec, etc.) grouped in lines so near one another that they almost touch, this widespread occurrence in all the geological formations, independent of the age and the facies, constitute characteristics that, through their generality alone, exclude the admission of any hypothesis that might connect the salt genetically with local geological phenomena as lagoon (32) or desert lakes (33). Besides, the insufficiency of these hypotheses is acknowledged by all who have studied the genesis of salt (5, 34, 35, 36).

All these considerations lead to the admission that the genesis of the salt cannot be connected with anything else than a world-wide phenomenon, the universal character of which might explain those universal characteristics of salt domes. And thus the author was led to connect the genesis of the salt with the hypothesis of saline precipitation on the surface of the first solid crust of the globe, in an atmosphere of a very high temperature (700°–800°) and very rich in vapors of chlorides at this temperature.

Later on, upon condensation the water separated these chlorides, on account of their solubility, and deposited them from these hot solutions in the existing depressions on the surface of the first crust. The temperature of the crust, being still very high, caused frequently re-evaporation of the water. Through re-solution and recrystallization, many times repeated on the surface of this first crust, there were formed numerous sedimentary deposits of salt, chemically pure, and of enormous extent and thickness.

This hypothesis may, perhaps, explain all the peculiar physicochemical and mineralogical characteristics of the salt, as well as the widespread appearance of the salt domes on the whole surface of the earth, in a manner identical genetically and in most of the known geological formations. The first ocean that originated through the precipitation of the greatest part of the water of the primitive atmosphere, having dissolved (until saturation) a small part of these saline deposits, covered them with the first marine sediments that were deposited over the salt and protected them from any further destruction. Tectonic movements have caused the salt masses to pierce the entire series of overlying sedimentary formations.

It is the sincere wish of the author that the exact geologic data set forth in this article, with regard to the mode of appearance of the rock-salt masses in the Carpathian region, which cannot longer be considered as Miocene, as well as the hypothesis of the genesis of the rock-salt masses generally, may contribute something to the solution of the important problem of the salt domes.

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DISCUSSION

W. A. J. M. VAN WATERSCHOOT VAN DER GRACHT: The description of the Rumanian salt domes and the hypothesis of the origin of the domes which Professor Voiteşti has presented are interesting but I cannot at all adhere to his theory. I believe that his explanation is not possible, and also that, if it were possible, it is not necessary to resort to such a hypothesis.

PROFESSOR VOITEŞTI'S THEORY IS NOT POSSIBLE

Professor Voiteşti's original salt deposits of the primary crust should occur in the highly metamorphic and intensely folded rocks, which we encounter everywhere over the globe, below the great major, and practically omnipresent, unconformity, which occurs at the base of the oldest known Azoic and Paleozoic sediments.

Invariably the rocks below this major unconformity, which apparently marks a very decided datum in the evolution of the earth, are very highly metamorphosed; they are principally, if not exclusively, crystalline schists, gneisses, and marbles, with enormous intrusions of old igneous rocks.

This series, of unknown but certainly tremendous thickness, probably does not yet constitute the primary crust, but is nothing else than highly metamorphosed very old sediments and intrusives. This whole series has been universally and intensely folded.

If, as is very possible, salt was ever laid down in these original sediments, it must either have become largely absorbed during the process of intense metamorphism, or, being plastic, must have been squeezed out entirely, before the great pre-Cambrian abrasion and subsequent unconformity. If salt ever was squeezed out as saline plugs by tectonic forces, the event must have been a result of the immense stresses manifested in these archaic rocks.

In consequence, it seems a practical impossibility to me that any rock salt, as such, was left in this archaic series by the time the oldest less metamorphosed sediments were being laid down over this primary unconformity. I am not aware, that, even in the oldest pre-Cambrian and Cambrian beds overlying the unconformity, any salt deposits are known; the oldest saline formations belong to the Silurian,[1] and these are, at least in part, truly sedimentary, and anyway clearly the results of evaporation to dryness of bodies of salt water. The older a salt deposit, the more chance that it has become tectonically displaced, or dissolved by the action of subsurface waters.

Wherever we find salt domes over the world, we know that there is present below them some formation, showing a saline or at least a continental facies. This is the case in Southeastern Europe, notably in the Carpathians. At the end of the Flysch period there occurred in the entire system of geosynclines of southern Eurasia, and among the mountain chains, which are rising up within them, a breaking up of the original Thetis Ocean into separate basins, and many of these show clear indications that they were subject to intense evaporation. Dr. Voiteşti advances reasons why the salt of the Carpathians did not originate in the Miocene. This is a point for separate discussion in a later paragraph. Here I merely want to emphasize that in Southeastern Europe and the adjacent regions of Asia a saline facies is fairly prevalent, immediately succeeding the Flysch period (Cretaceous-Paleogene).

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[1] Large Cambrian deposits of salt are reported in the salt range of the Punjab, India, but it is possible that these are younger deposits overridden by a thrust fault.—EDITOR.

We do not know the exact origin of the salt in the plugs of the domes surrounding the northwestern shores of the Gulf of Mexico, but here also there exist various possibilities for the presence of formations in a saline facies. Such possibilities exist in the Lower Cretaceous (with red beds and anhydrite) and in the Jurassic (I draw attention here to the occurrence of Jurassic red beds in Mexico in the Huizachal Valley, about 25 km. southwest of Victoria). There is a possibility that saliferous Permian might even be developed in this region, although it is not very probable. It is not absolutely impossible that a Permian basin of this kind should occur over the abraded interior ranges of the Paleozoic mountain system, which evidently underlies these regions, because we have a similar occurrence of this nature in the Gulf of the St. Lawrence (Permian red beds of Prince Edward Island and the Magdalen Islands).

The salt domes in Anatolia, Egypt, and Persia also occur in a region where a saline facies is widely prevalent in the Upper Tertiary, immediately succeeding the Nummulitic. The saline manifestations of the southern Atlas are connected with Triassic red beds, consequently probably with a saline facies.

The salt domes of Northwestern Germany are known to arise out of an enormous blanket deposit of sedimentary rock salt, occurring in several layers, each being hundreds of feet thick, in the Permian and Lower Triassic series, deposited in a great inland basin of red beds, which extends from Poland to the midlands of England.

A similar basin, although salt domes are not known in it (possibly due to the absence of sufficiently strong, lateral tectonic stresses), is known to exist in the western mid-continent of the United States, under the states of Nebraska, Kansas, Oklahoma, and western Texas. Here also several hundreds of feet of clearly sedimentary rock salt is intercalated as a blanket deposit in Permian sediments, evidently the result of the evaporation of a great inland sea.

A similar considerable blanket deposit of rock salt, clearly also a result of evaporation, is known in Alsatia and adjacent regions of Germany. This deposit is of Oligocene age.

It is quite clear, therefore, that in several regions of the globe great blanket deposits of undoubtedly sedimentary rock salt are known, as the result of the evaporation of great bodies of salt water, containing large quantities of sodium chloride, and occasionally, but much more rarely, of salts of other elements; the total bulk of these sedimentary salt deposits is certainly in excess of that present in the saline plugs wherever known. Fairly pure sodium chloride is the result of the main cycle of evaporation; other salts, notably of potassium and magnesium, are only laid down after the bulk of the sodium chloride has been deposited, and are only found in the depressions, where these final residue solutions have concentrated.

Some of these blanket deposits, notably the Permian salt layers of Northwestern Germany, give birth to saline plugs, because they have been subjected to sufficient lateral tectonic pressure, in addition to the pressure caused by the weight of the overlying formations. This latter weight, apparently, is insufficient, because in other basins, notably that of the mid-continent where a similar weight is present, but sufficiently strong lateral tectonic pressure is not indicated, salt domes apparently have not originated. In consequence, we must assume that in regions where these tectonic stresses have been still much more violent than in the moderately disturbed salt basins of Northwestern Germany, little will have remained of the original sedimentary salt deposit, whether this was a great continuous blanket, like that of Northwestern Germany or of the western mid-continent of the United States, or possibly only isolated salt lenses, the result of the evaporation of minor remnants of an inland sea-arm, or of continental salt lakes.

It is conceivable that in a region subject to such enormous tectonic forces as those which affected the great geosynclines of the Thetis, all along southern Eurasia, nothing at all has remained of original sedimentary salt bodies, which may have been displaced in their entirety, and that whatever salt we find now, is present exclusively as intrusive masses, or, in other words, saline plugs. This may explain why in such intensely compressed regions no sedimentary salt deposits are now found, but it does not mean that they never existed.

If it were true that the intrusive salt masses of the world originated out of the Archaic, we could not explain why salt plugs, although numerous and widely distributed, are nevertheless confined to certain regions of the globe and to certain mountain chains, like the Atlas, the eastern Alps, the Carpathians, and the mountains of Anatolia and Iran; and it would be difficult to explain why, for instance, they are absent in the entire great Cordilleran chain of the Northern and Southern American continents and other mountain systems of the same (generally Tertiary-Cretaceous) age of diastrophism; why also they should be absent over most of the mountain masses of the Permo-Carboniferous and older Paleozoic phases of folding, which occurred at periods when these original archaic salt deposits were less deeply buried and more easily extruded. There are many large mountain systems of these older periods, like the Sudetians underlying part of the Carpathians, in localities which have not been refolded by newer Tertiary diastrophism.

If the salt domes of the North German plain were not of Permian but of Archaic origin, why should they occur only where we know the region to be underlaid by a saliferous Permian, and not, for instance, to the south of the saline facies of the Permian, or within the Permo-Carboniferous Varisco-Armorican chains of Southern and Southwestern Germany, France, Belgium, England, and Ireland?

ARE THE SALT PLUGS OF THE CARPATHIAN REGION OLDER THAN MIOCENE?

So much as to the improbability, if not the impossibility of accepting the Archaic origin of the salt. We will now see whether the observations on the salt domes of the Carpathians make inevitable the assumption that these saline plugs are older than the saline facies of the Tertiary, immediately succeeding the Flysch period.

As Professor Voiteşti states correctly, until lately it has been generally accepted by Carpathian geologists that the salt masses in the Carpathian region as well as those of the eastern Alps, originated from a saline formation in the Miocene, immediately succeeding the Flysch period of this area. Professor Voiteşti contests this on the grounds that the breccia, regularly accompanying the salt plugs, contains numerous rocks belonging to formations older than the Miocene. These older rocks are especially abundant in the breccia of salt plugs occurring in, or very near, the Flysch belt of the Carpathians, but they are also found in other, farther outlying salt domes. Assuming correctly that this breccia results from rocks which the salt plug has pierced on its way to the surface, Professor Voiteşti draws the conclusion that the salt mass, having apparently pierced formations older than Miocene, must be older itself, and must have originated anterior to any of the formations represented in the breccia.

He also points to the fact that, in the Miocene itself, neither blanket nor lenticular masses of salt, which can be considered as sedimentary and in place, are found, but that all the salt in the Miocene has evidently been displaced, and only occupies its present position after considerable relative movement.

As stated previously in this memorandum, there occurs all over Southeastern Europe and adjacent regions in Asia a facies of the regression of the sea immediately succeeding the Cretaceous and older Tertiary Flysch period of the Tertiary mountain systems. Earth movements took place here from early Cretaceous time forward. In the marginal chains, of more recent date than the interior ranges, these movements increased progressively to reach their culmination only in the Pliocene and the early Quaternary.

At the end of the Flysch period, the geosynclinal sea not only regressed, but was divided into several basins by the progressive earth movements; some basins were entirely cut off from the main sea, while others had only very restricted connections. Apparently, climatic conditions contributed toward active evaporation, with the result that all over this region of Eurasia we find evidences of a saline facies during this period. This does not mean that these saline deposits were absolutely contemporaneous in the different localities of this wide region; apparently they are not. Indications of salt occur in different localities from the Oligocene, and possibly the late Eocene, upward well into the Pliocene. It was a general period of salt lagoons and inland salt basins, and apparently in the Carpathian region this facies occurred in the Helvetian Miocene.

The fact that in the Miocene of the Carpathians we do not now find sedimentary masses of salt in place can very easily be explained. As I said before, the main diastrophism of the present Carpathians occurred after the deposition of the Miocene. In fact, the great overthrust sheets of the Carpathian front all override the Miocene throughout a wide area. This overthrust of gigantic sheets of Lower Tertiary, Cretaceous, and older formations over the Miocene, and subsequent folding all through the late Pliocene and early Quaternary, have subjected this Miocene substratum to enormous stresses. Although locally the Miocene does not seem to be overmuch disturbed along the Carpathian front, it is certain that the pressure to which it must have been subjected was enormous. These overthrust sheets formerly extended much farther than they do now, as their front has regressed considerably on account of erosion. The original front of these thrust sheets also has been pressed and involuted into the Miocene substratum. That this condition is of considerable extent is proved by the Flysch- *Klippen*, which are prominent in many localities, and to which Professor Voiteşti himself refers repeatedly.

Salt is a comparatively plastic mineral, and we know with certitude that whenever a sequence which contains salt beds is subjected to very strong tectonic forces, the salt is displaced and squeezed out as a plastic paste. That such interior movements in shale or clay sequences subject to great tectonic forces may be enormous is demonstrated ever more clearly as we obtain more detailed information regarding the structure and mechanism of great mountain chains. We know, for instance, how the massive limestone reefs, in the shaly Trias of the East Indian arcs, have been acting as stony kernels in a plastic mass, and how these enormous "batoes" have been practically shot through these shales over unbelievable distances by folding. Consequently, we cannot wonder that sedimentary salt lenses, which may have been contained in the Miocene along the front of the Carpathian thrust sheets, or underneath them, have been entirely squeezed out, and are in no place present any more in their original location, but everywhere are found tectonically displaced.

As said before, the Miocene underlies the older thrust sheets of the Carpathians over unknown distances, and has been involuted with older *Klippen* to an unknown extent. Moreover, when this Miocene was deposited, the interior chains of the Carpathians already stood out as large mountain masses, subject to active erosion to the extent, probably, that the interior had already become entirely peneplained. In consequence, material derived from these interior chains and their pre-Carpathian basement must be expected in the Miocene, and is known, in fact, in Miocene conglomerates.

Under these complex conditions, it is only natural that the breccia surrounding the salt plugs should contain fragments of a variety of formations, regardless of the relative ages in an undisturbed sequence, the only requirement being that the intrusive salt and the various formations have come into contact. Many of these salt plugs appear in erosional windows in the thrust sheets, showing Miocene, without it being possible to state definitely whether this latter is the undisturbed autochtonous substratum, or whether these masses of Miocene are either involuted in, or sheared along, under the thrust sheets. A great many plugs finally pierce the Flysch thrust sheets themselves, apparently rising up from the autochtone underneath them, which, most probably, is Miocene.

I am not familiar with the more recent work in the Carpathians, and I will not go into a detailed discussion of the various individual salt domes. I gather, however, from Dr. Voiteşti's paper, and from other publications, that the pre-Miocene rocks are most conspicuous in the breccia of the salt plugs which occur within the outer front of the Carpathians, or immediately in advance of the front, and that, with the exception of pre-Flysch formations belonging to the Jurassic or the older basement, they are less conspicuous in the outlying domes.

Here I must state again that, in general, we do not know how far the original overthrusted Carpathian front stood in advance of the present front of the Flysch sheets, and neither do we know the conditions at depth in the foreland—notably in the depression between the sub-Carpathians and the Dobrudja.

In conclusion, I still hold to the theory that the salt of the Carpathian plugs is Miocene, for the following reasons: (1) it is the only formation in the entire sequence which we know to contain a saline facies; (2) the saline facies may not contain actual beds of salt *in situ*, but the enormous tectonic forces, to which this sequence has been submitted, easily explains that all the plastic salt must have been tectonically displaced; (3) the presence of pre-Miocene rocks in the breccia, surrounding the salt plugs, can be explained as derived from overlying thrust sheets, which the salt has pierced, or *Klippen*, which it has encountered, or from conglomerates, derived from the older Carpathian chains, occurring within the Miocene; (4) I cannot conceive the origin of the salt to have been in the pre-Miocene sequence of the Carpathian geosyncline, nor in the pre-Carpathian Paleozoic of the underlying Permo-Carboniferous Sudetic-Dobrudjan chains, which give no evidence anywhere of a saline facies in their sequence, or of the occurrence of salt plugs anywhere outside of the Carpathian structure; (5) a still older origin of the salt plugs from the archaic crust seems entirely at variance with what we might expect.

RUMANIAN OIL FIELDS

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ABSTRACT

The distribution of the Rumanian oil fields is governed by lines of folding related to the major Carpathian overthrust faulting. Along these lines of folding, the production tends to focus around salt masses that form local "highs." The source of the salt is unknown. Its rise is due to lateral pressure. The source of the oil is disputed, but the writer believes that it is Pliocene.

A comparison of these fields with those of the American Gulf Coast region shows that, although there are some resemblances which may indicate the action of like causes to a limited extent, the dissimilarities are greater. The lateral pressure, which is proved for Rumania, cannot be accepted as the entire, or even as the major, cause of the American domes.

INTRODUCTION

Geologists working on the problems of the Gulf Coast salt domes have drawn their European analogies mainly from the North German salt region. The occurrence of the salt in Germany has been adequately described in available publications. It differs from that in the American salt domes in the presence of associated "mother-salts" and the lack of any considerable oil production. The greater similarity of Rumanian conditions has been recognized but, on account of the lack of detailed information, the references have been vague or scanty. The following summary of the Rumanian oil region, as it is understood today, is written to show in what respects a comparison might be helpful.

The kindness of the Rumanian geologists, particularly Professor Murgoci, enabled the writer to go over most of the reports on these fields during three months spent in that country. It is mainly as a compilation of this material that the present article is written.

The region discussed comprises the old Rumanian provinces of Wallachia and Moldavia. Although there are prospects in Transylvania, those two provinces compose the entire oil-producing area of the country.

AREAL GEOLOGY

The region is divided into three zones. On the north and west, the Carpathian mountain system is composed of crystalline metamorphic rocks with igneous intrusions, and of twisted and distorted remnants of Jurassic and Cretaceous sediments. On the south and east lies the Rumanian Plain, formed by the horizontal beds of

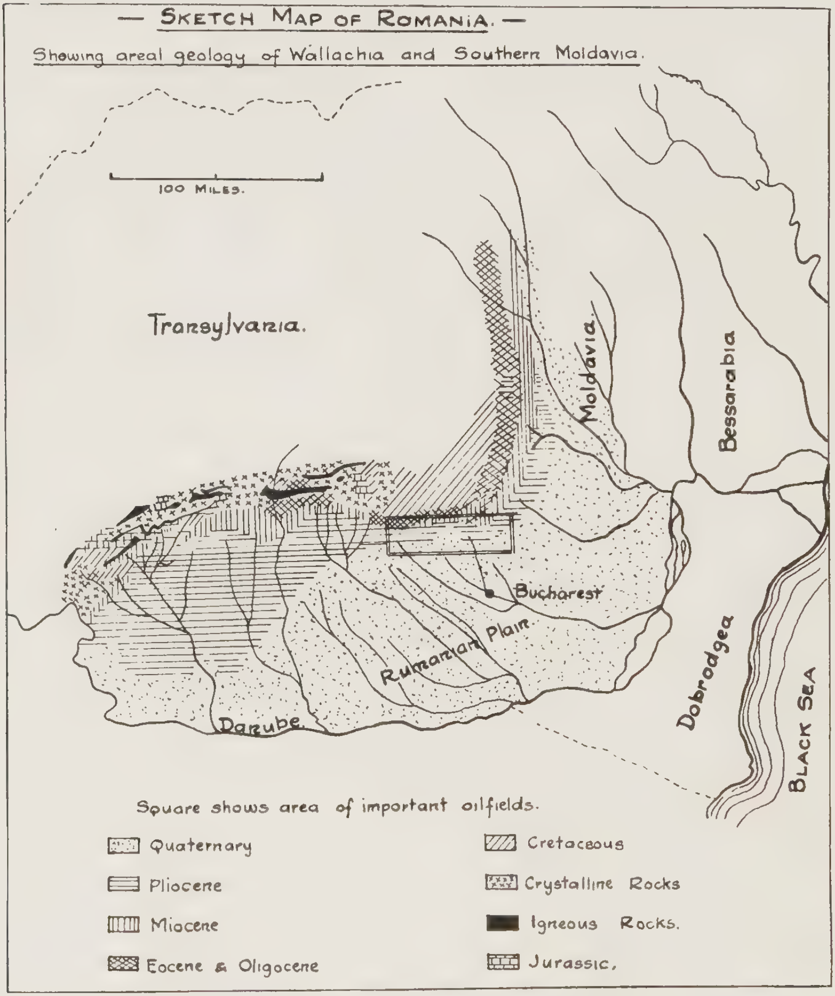

FIG. 1

the Quaternary. Between these two zones, the broad band of foothills marks the area of folded Tertiary strata.

STRUCTURAL GEOLOGY

Great overthrust faults are the dominant structural features. They are explained by the position of the region on the eastern edge of the great Alpine movements. When, from overloading or other cause, the portion of the earth's crust composing the Greater Alps attempted to expand laterally, it encountered resistant earth masses. As a result, the outer edges of the expanding crust were out and over the stationary masses in great sheet overthrusts or "nappes." One of these movements occurred in mid-Cretaceous time, forming what are known as the "crystalline nappes." Another in mid-Miocene formed those distinguished as "Flysch nappes." This overthrusting was also of importance in its tendency to predetermine the type and direction of later movement.

The post-Pliocene Carpathian movement had the greatest direct effect on conditions in the oil region. With the appearance of the Carpathian Mountains during this interval, a series of paralleling folds was formed throughout the Tertiary belt. These folds extend for great distances but are so frequently broken by the steep plunging of the axes that they might be considered as chains of separate anticlines. At the same time that these were formed, salt masses appeared at the surface, most of them coinciding with the structural highs of the folds.

STRATIGRAPHY

The stratigraphy of the Cenozoic formation is given in some detail because of their relation to the occurrence of the oil:

QUATERNARY

Recent—Gravels, loose clays, and sands.
Pleistocene—Gravels and loess.

TERTIARY

Pliocene

Levantine—Yellow gray, clay, sands, and gravels.
Dacian—Gray to brown and black shaly marls, lignite beds, and several loose sands.

Pontian—Light greenish-blue marls, very little sand.

Maoetian—Slate-colored marls darkened with organic remains, with very softs andstones. (This description applies only to certain areas in the vicnity of the oil fields.)

Miocene

Sarmatian—Basal conglomerates and sandstones, and dark blue marls with thin gypsum beds.

Tortonian—lacking in most places, some thin limestone fragments.

Helvetian—Blue-gray marls and soft sandstones, gypsum, and dacitic tufa.

Burdigalian—Conglomerates and transgressive sandstones.

Oligocene

Upper—Massive porous sandstone.

Middle—Black disodylic[1] and menelitic[2] shales, very carbonaceous, but showing considerable diagenetic menelite, hornstone, and amber. (The same shales are regarded as source beds of the Galician oils in the north.)

Lower—Gray marls and soft sandstones.

Eocene

Sandstones, one massive and porous, gray marls, locally black or violet red.

The beds below mid-Cretaceous are of marine origin. Between these and the mid-Miocene, the formations are deposits from alternating mediterranean seas. Above these, the upper Tertiary beds were deposited by a succession of great "lakes" of variable salinity.

SALT

Distribution of salt.—The salt masses are scattered from the edge of the Quaternary across the mountains into Transylvania. Although they cannot be limited to any given geological area, the maximum occurrence of the salt masses coincides with the edge of the nappes (16),[3] and they tend to fall into general lines curving parallel to the Carpathians. The presence of unknown masses under the great thickness of recent beds in the Rumanian Plain is not unlikely.

The stratigraphic location of these masses is uncertain. Their position, piercing the youngest Tertiary beds, dates their appearance as post-Pliocene, but their base is unknown. No given formation has been proved definitely to be below them.

[1] A local term for black flint, hornstone, etc.

[2] Menelite is an opaque variety of very dark opal in these shales.

[3] Numbers in parentheses refer to bibliography at end of article.

The majority of these masses lie on lines of uplift, but there are exceptions. A few occur in synclinal areas or cutting at right angles across anticlines.

The masses are most numerous along the edges of the overthrusts, but the great interest lies with those appearing as "salt domes" in the outer, oil-bearing belt. These "domes" are found on the lines of post-Pliocene folding which extend in a series across the Tertiary belt to disappear under the Quaternary. The Tzintea, Baicoi, Floreshti, Moreni, Gura-Ocnitzei structure is a typical example of such a fold. It is known only by these long domes lying in a curved line, with their probable connections buried under flat alluvium. Salt masses have been found in four of these anticlines and oil in four; the most important of the oil fields, Moreni and Baicoi, have salt "cores."

Form of the salt.—On the surface, salt springs and ponds are the most characteristic markings of these masses. Mounds of the Gulf Coast type are unknown. Occasionally the surface above a dome is pitted by numerous shallow basins ("dolines").

The masses are roughly ellipsoidal, with their greater horizontal axis parallel to the direction of the fold, even curving with it. The sides are flexed but more or less vertical, one side usually showing the typical overthrust lip at the top. Thus the wells on the overthrust side pass from the recent beds into the salt and go through that before reaching the Tertiary formations and production. The thickness of the salt here increases as the main body is approached. All tests in the main part of the core have been abandoned, still in the salt; depths of more than 1,800 feet were recorded. On the opposite side, wells that start in the salt never pass out of it, and those nearby seldom strike it. Occasionally one reaches a bulge down on the side and even passes through it. This is likely to show a considerable thickness of salt (700-800 feet), and yet the adjoining wells find nothing, showing that the projection was flexure curving only slightly from the vertical.

Mrazec named these structures with salt "cores" "diapyr folds," a term based on the supposed mode of formation rather than the resulting form. With many inclusions, this term has become ambiguous.

Composition.—Chemically, the salt is almost pure sodium chloride (98–99.9 per cent), but many impurities in the form of clays, sands, and carbonaceous material have been folded in mechanically. Although scattered more or less throughout the mass, this débris occurs in greatest quantities near the top. It shows the same wavy lines of rock-flow type described in other countries.

Gypsum and anhydrite fragments may be found with the débris, but their only known occurrence as beds is where they are in place in the Helvetian formation that adjoins the mass. There is no definite layer of such material associated with the salt body, which might be compared to "cap-rock."

The reported occurrence of carnallite in the vicinity of Targu Ocna (11) constitutes the sole indication of mother-salts. Sulphur springs are common, some near the masses, but there is no apparent correlation.

Theories concerning salt.—The distribution of the salt masses, mainly on lines of uplift but with some in other positions, can be explained if it is supposed that the salt bodies, prior to the movement that brought them to the surface, were scattered irregularly throughout the region. During the formation of the folds, the pressure was temporarily great enough to cause the salt to flow. Most of the salt masses in this semi-fluid condition could migrate along their plane to the points of greatest relief, the major tectonic lines. And it is along these lines, with or without previous faulting, that the most favorable conditions were found for the ascension through the overlying beds to the surface.

Formation of the salt by precipitation from ascending solutions is precluded by this supposition. Its rise as a solid, but plastic, body is proved by its flattened, undulating form, by its position in the folds, curving back to the adjoining beds under its overthrust, and by the pinching of strata remnants in little synclines on its top. The synchronous appearance of the domes throughout the country in post-Pliocene time may be taken as confirmatory evidence. Even the great amount of sand, clay, and so forth, twisted into them accords well with this.

Lateral pressure is indicated clearly as the force which caused this rise. It caused the great Alpine movements of the earlier periods, which had predominant influence even in this outlying region, where it was less intensive and the results not as clearly marked. The asymmetric anticlines and great reverse faults show that the Carpathian movement, during which the salt appeared, had the same origin. Finally, its effect is shown by the shape of the masses themselves, flattened and with overthrust lips.

There are several hypotheses as to how lateral pressure produced this rise. Those who attribute the greatest importance to the formation of the nappes in explaining the geology would look on this as the result of a similar phenomenon. The hypothesis would be that great reverse faults brought the salt, in its natural stratigraphic position, to the surface, where it was above the uppermost bed of the downthrust side. Then in the reaction from this overthrusting there would be a movement in normal direction, and the upthrust beds would sink back toward their former position. The salt, however, being more plastic, would be pinched in the fault area and remain at the surface, surrounded by younger beds.

The form of many "domes" falls in excellently with this theory, even having the lip overthrust in the direction of major movement, although there are some cases where it goes the other way. Thrust faults are practically universal, but while certain domes have a much older formation on the upthrust side, there are many with the youngest Pliocene formation on both sides, necessitating the complete return of the enormous throw (equal, at least, to the thickness of all Tertiary and Mesozoic strata) which would be necessary to raise the salt to the surface. This might be avoided, however, by postulating an upward movement of the salt in the fault planes. The exceptional cases, where the masses come to the surface at other points than the center of the structure, are not easily explained.

Kraus has advanced an interesting hypothesis. By the resolution of a force, such as the downward push of a settling area, he obtains a lateral thrust which follows a logarithmic curve. Shaw's Mississippi mud lumps are used as an example of such action at present. As Kraus points out, the characteristic form of the salt masses approximates the mathematical result as closely as could be expected when allowance is made for the other factors.

Although there is a lack of definite statements in the literature, it is probable that the majority of the geologists believe that the salt, at the lines of folding, found the least pressure from above and so moved in that direction.

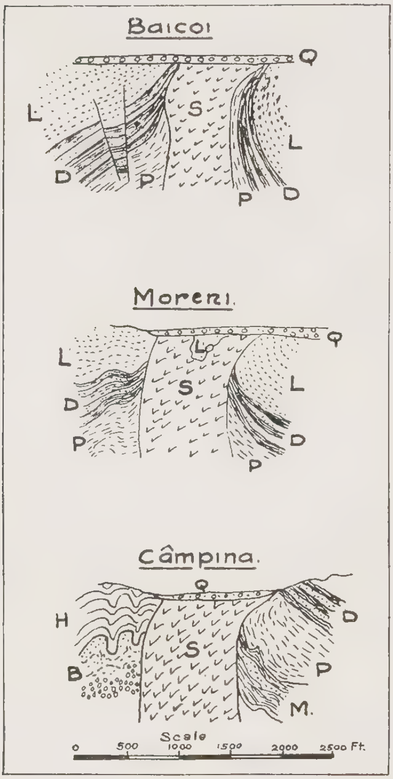

FIG. 2.—Cross-sections of typical Rumanian oil fields. *Q*, Recent; L, Levantine; *D*, Dacian; *P*, Pontian; *M*, Maeotian; *H*, Helvetian; *B*, Burdigalian; *S*, Salt.

The origin of the salt is unknown. It is generally regarded as coming from deposits in marine formations. Prior to the last five years, it was firmly held to have originated in the receding mediterraneans of the Miocene, therefore known as the "Salifere." This opinion is still held by some (1), although recent work has generally discredited it. But nothing has been found to show the actual source.

P. Voitestiti (16–19), whose work has been most important on this phase, after freeing the salt from its traditional place in the Miocene, moved the source down successively through the Cretaceous and Permian, until finally he suggested a precipitation on the cooling earth-crust as a possible origin. The vulcanists, from the days of Coquand (2), one of the earliest workers on these problems, have claimed that it is from emanations of volcanoes as yet unknown in this region.

OIL

Occurrence.—All the production comes from the Tertiary of the sub-Carpathian region, although signs of petroleum have been found in the Cretaceous and lower Tertiary in the mountains. Of this production, about 3 per cent comes from the Middle Tertiary of the northern curve (Moldavia), the rest from the Pliocene of the southern curve, the district of typical "salt dome" oil fields. Because of fracturing, traces of oil have been found in practically every horizon. All the production, however, is limited to the Kliwa sandstone of the Oligocene, and the Maoetian and Dacian horizons of the Pliocene; over 95 per cent of the total, roughly, is divided between the last two.

Attempts have been made to differentiate the oils from the different horizons by their composition, but aside from the general tendency of Dacian oil to be heaviest, nothing has been shown. There is more difference between fields than between horizons.

All the oil is produced from well-marked uplifts. Those with salt "cores," being the areas of greatest folding, are the locations of maximum production. All the region is heavily faulted. The faults, together with minor irregularities of bedding, have a local influence on the distribution of oil on the fold. Great emphasis has been laid on these faults in connection with the migration theory, which would make them the essential factors for the presence of oil, and the fold merely an aid in retaining it.

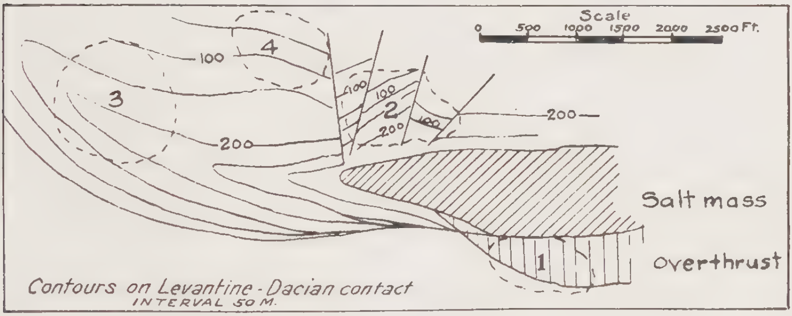
Scale
0 500 1000 1500 2000 2500 Ft.
100
4
3
2
100
100
200
100
200
200
Salt mass
1
Overthrust
Contours on Levantine-Dacian contact
INTERVAL 50 M.

FIG. 3.—Sketch of Baicoi. Producing areas: (1) Schela Veche, (2) Cotoiu, (3) Ferbatori, (4) New Extension.

Figure 3, showing the Baicoi field, gives an example of areas of production on one of these anticlines with a salt "core," and indicates the focusing effect of the major structure, and the irregularities induced by faults and minor phenomena.

The relation between salt and oil has been greatly stressed in Rumania. Mrazec considered the presence of salt, either solid or in solution, as the absolute requisite for the formation of petroleum, the oil here coming from "bituminous aureoles" formed about the masses. More recently, the adoption of the migration theory has led to the belief in the ascension of the oil along paths opened by the salt.

Practically, this has aided the efficiency of Rumanian oil geology. Although producing fields exist on simple anticlines in this region, by far the greatest amount of production comes from those inclosing salt masses. The heightening of the uplift, induced by the presence of the salt, correspondingly increases the likelihood of production. Thus the presence of salt is always of interest, and in cases where only flat recent terraces are exposed, the indications of such a mass give the best reasons for exploration. Murgoci's recent work at Floreshti gives an excellent example of the discovery of a salt mass solely from topographic evidence.

Source of the oil.—The source of the oil, like that of the salt, is a matter of contention. Mrazec's theory of origin about the salt mass named the Miocene strata, included with the masses as Salifere, as the source beds. This was generally accepted in spite of the absence of organic material in these strata. Migration was given as the cause of its appearance in horizons both above and below these. When opinion changed with regard to the source of the salt, this position was abandoned, and the oil source beds were looked for elsewhere.

P. Voitesti, in moving downward the source of the salt, continued to seek farther down for that of the oil. Although he does not place it definitely, the idea is given that he favors another precipitation, this time of petroleum, on the pre-Archean crust. Murgoci (10) has turned definitely to vulcanism, a theory which has always had more supporters in Rumania than in America. Except for the statement by Galician workers that the Moldavian oil comes from the same Oligocene beds as does their own production to the north, the other writers are vague in regard to the source, but invariably lay stress on migration to account for its present position.

Although the consensus of opinion is against it, the writer is inclined to favor an endogenetic source, the origin of the oil in Oligocene, Maoetian, and Dacian formations where it is found.

Those who support the migration theory have presented considerable evidence. They point out that the fossils of the producing formations are not marine types and that the presence of lignite beds in the Dacian shows fresh-water or deltaic conditions, while oil source beds in most of the world are considered as of marine origin. They show that the great amount of faulting would furnish the necessary migration planes. Unbroken anticlines are known where the Dacian is barren, and they claim, therefore, that this formation will be productive only where its upturned edge is pinched along the salt contact, where the oil has entered. In certain fields, the lower the sand, the larger the producing area and the greater the amount of oil produced. This fact has been mentioned as still further evidence that the oil comes from below.

In the writer's opinion, the endogenetic theory is at least equally applicable to the oil occurrences so far as they are known. This was originally suggested by an examination of the stratigraphic column, where clay and shales resembling, in their texture and carbonaceous content, the beds which are considered as the source of oil in American fields were found only in the producing formations. It seemed unlikely that oil should ascend from below and, merely by accident, find reservoirs there. Then, in certain fields, some of the sands are lenticular, and production has been found where the sand body is completely isolated from breaks that would give access to rising oil. Only one or two unbroken anticlines, and these comparatively small, have been tested. Although no oil was found in the Dacian, it was found in small quantities in the Maoetian, which is usually the greatest producer. The relative lack of success could be laid to the relative gentleness of the folds. As for the pinching of the upturned edges of the producing formations, which was considered essential for the presence of oil, this very pinching would seem to prevent migration down the slope of the strata from the salt contact as it has aided in preventing its escape up the slope.

Finally, although there is much yet to be learned, the adoption of this theory has the advantage of furnishing a much simpler working hypothesis.

RUMANIA AND THE GULF COAST

The chief similarity of the Rumanian oil fields to those of the Gulf Coast is, of course, the accumulation of oil on structures having salt cores. The salt is the same, practically pure sodium chloride, with extraneous inclusions and "rock flow" lines, and without the potassium and other salts of the German deposits. It has appeared in its present position from a source that is also unknown. The resemblance of form of typical masses is limited to the fact that their surfaces are small in comparison to their great depths.

The differences arise from the incomparably greater movement which is manifest in Rumania. Thus there is a series of well-defined, steep folds throughout the region, instead of the normal low-dipping strata of the Gulf Coast, disturbed only in the immediate vicinity of the salt. The salt masses themselves have been flattened parallel to the anticlinal axes and overthrust above the steeper side. This deformation illustrates clearly the effect of the force which caused the rise of the salt on the mass itself, when it is contrasted with the unchanged, circular plugs of our own fields.

Whereas the upward movement of the Gulf salt seems to have occurred at various times, including the present, the rise of the Rumanian salt is restricted to the post-Pliocene interval.

There is no "cap-rock" in Rumania, such as that in the Gulf Coast. Lacking this, and with no covering but the loosely consolidated Recent beds, oil never accumulates on top of the salt.

CONCLUSION

Thus, a summary of conditions in this other region producing oil from salt-cored structures shows more disparity than similarity. It furnishes an example of a region where the "domes" evidently were formed by the force of lateral pressure, and the similarities which exist may show a certain amount of causal relationship. The preponderating difference, however, would justify those who believe that other forces are mainly responsible for the existence of the Gulf Coast domes.

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THE UPTHRUST OF THE SALT MASSES OF GERMANY[1]

HANS STILLE

ABSTRACT

The Zechstein salt deposits of middle and northern Germany were laid down in a sinking basin in which sinking came to an end during the Jurassic, except in northern Germany, where it persisted into the late Tertiary. The beds deposited in this basin were involved in the Saxon mountain-building movements, which contrast with the older, Variscan movements in being intermediate in character between folding and block faulting. The Saxon movements were periodic and not continuous. That the movements were due to compressive thrust is shown by the fact that the "horsts" were uplifted.

The salt bodies are found in the form of "salt beds," "salt anticlines," and "salt stocks." "Salt anticlines" are normal anticlines both in the form and inner structure of the salt and in the structure of the sedimentary cover. The "salt stocks" are strongly folded, subcircular to elongated masses of salt which are upthrust into faulted rather than folded adjacent formations.

The main theories proposed to explain the upthrust of the salt are three: Lachmann's "atectonic" theory, the "isostatic" theory, and the theory of upthrust by lateral thrust. Lachmann's "atectonic" theory of upthrust of the salt by an inherent autoplastic force is no longer current. The formation of the salt anticlines by the compressive thrust of the Saxon orogenic movements is very generally accepted by German geologists. But as there is every gradation in form between the characteristic salt anticline and characteristic salt stock, as the gradation from one to the other can be followed on the same anticlinal axis, and as with a rare exception the periods of movement in the salt stocks coincide with the periods of the Saxon orogenic movements, it seems reasonable to believe that all have been caused by the same force. The difference in the resulting forms is due rather to the difference in the materials acted upon than to difference in the forces acting. The salt is more plastic and therefore more mobile than the ordinary sedimentary rocks, and is therefore the more easily deformed. Under intensive deformation, it advances far ahead of the other rocks, and thus a salt stock is the extreme form of an anticlinal core. The tectonics of salt upthrust are therefore a phase of the tectonics of mobile materials and are intermediate between the normal tectonics of folding and the tectonics of magmatic intrusion.

D. C. B.

THE FORMATION AND SECULAR SINKING OF THE ZECHSTEIN SALT

The folding of the Variscan mountain system which traversed middle Europe in the later Paleozoic was succeeded by depression which prepared a broad basin into which the sea penetrated at the beginning of Zechstein time. The extent of this sea in German territory can be seen from Figure 1. Toward the northwest it stretched to middle England; toward the east it had a broad connection with the Russian late Permian basin. This Zechstein sea has left behind the most widely extended salt deposit that has ever been formed in the course of the earth's history. A valuable feature of this salt deposit is its well-known succession of beds of potash salts, which were deposited principally in the German portion of the great basin, in general in a single series, but in certain areas, in two series.

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[1] Translated from the German by Donald C. Barton.

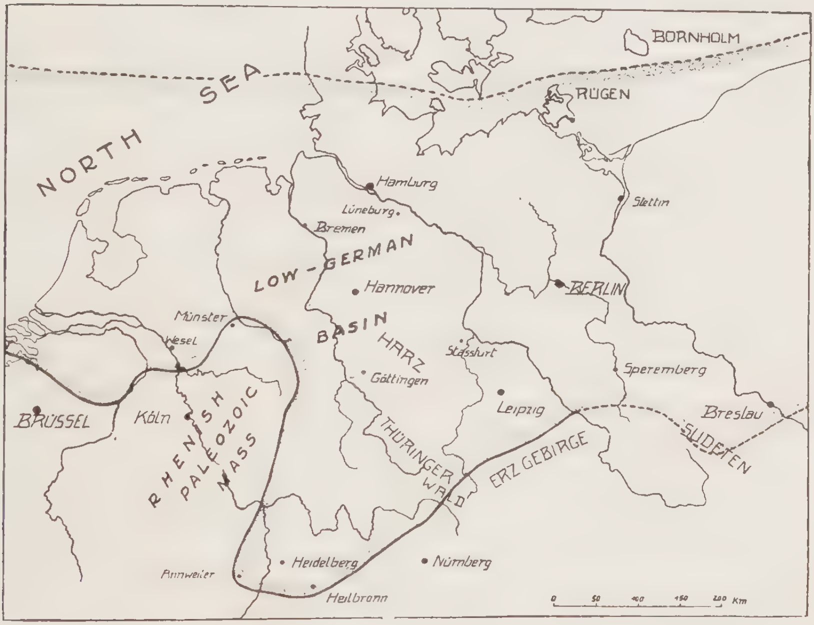

FIG. 1.—Map showing the probable extent of the German Zechstein Sea

The Zechstein was followed by the Trias; the great basin, which had become land during the formation of the salt deposits at the end of the Zechstein, broadened into the basin of the Germanic Trias, and within those extended boundaries the sinking movement continued. Buntsandstein, Muschelkalk and Keuper were deposited above the Zechstein salts, which sank correspondingly. Even in the older Jurassic, this sinking process continued generally, but began to be differentiated. In the southern and middle portion of the former

Zechstein area, the sinking gradually came to an end; while in the north, in the "North German basin," it continued. There, Dogger and Malm, Cretaceous and Tertiary were deposited in great thickness, although farther south, in the area which formed the "Middle German continent" of that time, these beds are wholly or almost wholly lacking. In the north the salt sank many thousands of meters below the surface; in many portions of the "North German basin," the lower Cretaceous alone has a thickness of over a thousand meters. The great thickness of this sedimentation indicates the "North German basin" especially, as well as the Zechstein-Triassic basin in general, as a geosyncline, if by "geosyncline" we understand broadly a secularly sinking area of sedimentation without regard to the character of the sedimentation which took place in it, without regard to its shape, and without regard to the form of the mountain-building which affected it. By the sinking that has been described and by burial under an ever increasing mass of sediments, the salt reached, in the course of time, warmer and warmer regions. The salt compounds, formed at the temperature of the Zechstein times, in part became no longer stable; varied thermo-metamorphism set in (21, 23)[1] and changed the original composition and structure; thus the paragenesis, sylvinite-kieserite, which as *Hartsalz* is widely extended through the German salt deposits and which can form only above 72° C., can be explained according to Arrhenius' theory (2, 3) as the result of thermo-metamorphism consequent upon the geosynclinal sinking of the Zechstein salt. From the thickness of the overlying sedimentary cover of that time and from the geothermal gradiant, it is possible to calculate at about what time the *Hartsalz* of the various portions of the Germanic basin formed from the original salt compounds. Beneath the present southern Hannover area this must have happened about during Lias times.

THE SAXON MOUNTAIN-BUILDING OF GERMANY, THE FRAME OF THE TECTONIC DEFORMATION OF THE SALT MASSES

The *downward movement* of the salt was of varying intensity. In the "North German basin" it carried the salt several thousand meters below sea level. In Middle Germany, in those areas which since Dogger times have belonged to the Middle German continent, it was of far less intensity.

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[1] Numbers in parentheses refer to the bibliography at the end of the paper.

The *uplift* of the salt to the levels at which wells and shafts now reach it stands in the closest dependence upon the "Saxon" mountain-building.

Two great mountain systems are to be distinguished in the subsurface structure of Germany. The older, the Variscan, has already been mentioned; it was obliterated at the end of the Paleozoic. The younger is the Saxon, which in form, is widely different from the older. If the older can be said to be true folding ("Alpine type" of mountain-building), the younger can be said to have expressed itself in faulting ("Germanic type" of mountain-building) with subordinate folding. Yet in the "block terrane" of Germany it is possible to recognize an arrangement of structure along certain lines of uplift and depression, just as in folded mountains the strata are elevated along certain lines (anticlinal axes) and depressed along others (synclinal axes). The Saxon mountain-building consequently has as its basis a certain fold plan in which the folds, in contrast to the normal type of folding, are allied in strong degree, already *in statu nascendi*, with faults (compare Fig. 2). They are spoken of in this sense as "fault folds" (Bruchfalten), which in the series of tectonic forms take an intermediate position between true folds and block faults.

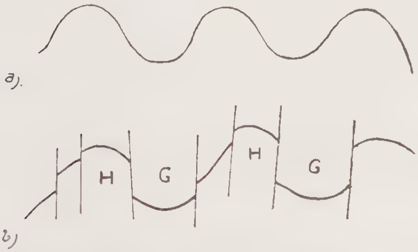

FIG. 2.—Diagrammatic sketch illustrating: (*a*) normal folding, and (*b*) fault-folding.

The conception that lateral pressure had created the Saxon "fault-folding" was strongly contested up to about ten years ago, but at present it seems to have found general acceptance among the German geologists. The deviation of the forms from the normal forms of folding, especially through the cutting of the folds by a host of faults, may be explained by the increased stability which the subsurface had gained through the Variscan folding and by the magmatic-volcanic processes which took place with that folding and in consequence of it.

A normal fold of folded terrane and a fault-fold of the German block terrane are illustrated in Figure 2. In fault-folding, the horst (*H*) corresponds to the anticline of the normal folding, and the graben (*G*) corresponds to the syncline.

The Saxon mountain-building favored the southeast-northwest (Hercynian) direction. The Rhenish, north-south, direction also is strongly in evidence in a broad zone which lies east of the Rhenish mass of Paleozoic schists, in prolongation of the upper Rhine graben, and which extends far to the north past Hannover and Lüneburg into the area of the lower Elbe. A phenomenon which is of great significance in the explanation of the occurrences of the salt is abundantly recognizable: the intersection of the axes of elevation and depression of Hercynian and of Rhenish directions, respectively, give rise to interference phenomena, as, for example, an especially strong uplift where two zones of uplift cross, or an especially strong depression of the subsurface where two lines of depression cross. That the Saxon orogenesis, like orogenesis in general, took place in individual periods, broken by long periods of relative quiescence in which exclusively movements of epeirogenic character set in, is no longer contested from any side. These periods are recognized by the demonstrable angular unconformities within the sedimentary series of Germany. It thereby becomes recognizable that it is a question of the same periods which elsewhere in the world are evident in the late Mesozoic–Early Cenozoic time. Up to perhaps twenty years ago, it was believed that there were not more than two periods which came in the Miocene, but evidence has now been obtained of other, especially older, mountain-building, of which the earliest, the Cimmerian, took place in three subperiods at the end of the Jurassic. It corresponds to the Pacific revolution in America. Other periods followed in the Cretaceous, and a very important movement took place at the end of the Cretaceous and the beginning of the Tertiary, contemporaneously perhaps with the Laramide Revolution of North America. New orogenic movements set in at the end of the Eocene and Oligocene; several followed even in the late Tertiary; and in fact weak echos are evident in the Quaternary. In the orogenic periods, the beds which had gradually sunk during the preceding time and which had been correspondingly deeply buried under sediments were again moved upward in broad zones in the formation of a fault-fold system. Downward movement, however, soon set in again in many places, and after the fault-folds had been planed off by a denudation, they were covered anew. The renewed movement of depression then continued until another orogenic period brought about yet another movement of uplift. Thus it is possible to recognize in the North-German basin a repeated alternation of long-continued depression broken in certain zones and along certain lines by spontaneous upward movement.

James Hall recognized in North America as much as sixty-five years ago that folding sets in where the sediments are very thick that is, to use Dana's expression, in geosynclines, while the up-arched areas in which there was little or no sedimentation are spared by the folding. This fundamental law of mountain-building is proved true also among the lesser structural features of the Saxon areas. Where sedimentation did not take place after Variscan times or was small in amount, that is, where the sinking of the ground soon came to a stop, we have only weak Saxon mountain-building. Conversely, the folding was most intensive where, after the Variscan folding, the subsurface sank the deepest, and where, correspondingly, the younger sediments were deposited in the greatest thickness. Quite in the sense or in the extension of Hall's thought, in fact, it is possible to recognize in individual basins, as, for example, in the so-called sub-Hercynian basin, increases in the intensity of folding with increase in depth of the basin.

Since the upward movement of the salt masses is most closely connected with the Saxon fault-folding, and especially since tension phenomena are not lacking within the fault-folded zone, it may be asked whether the explanation of the fault-folds by lateral thrust is to be accepted unconditionally.

Edward Suess, as a matter of fact, in *The Face of the Earth*, wished to explain the German "block terrane" by differential downward movement according to the example of horsts and grabens. But subsequently it has become possible to divide the Mesozoic-Cenozoic tectonic processes into individual periods, and by comparison of the successive steps to win a deeper insight into the nature of the processes. Especially it has been shown that in the orogenic periods in which the faults and fault-folds arose, the rock masses affected in no case moved downward but instead moved upward. Beds which before the orogenic movements had lain deep below sea level, after those movements were exposed to sub-aerial denudation as part of the fault-fold system which had arisen in the meantime. Following peneplanation, the area was soon again covered by a new transgression. This problem, which is so important for a comprehensive conception of the Saxon mountain-building, was discussed more in detail by the author in 1911 (32).

In this Saxon folding the terrane which was being changed over into a fault-fold mountain system was moved upward and, in fact, differentially, just as in true folding a differential upward movement takes place, stronger in the anticlines and somewhat weaker in the synclines. The graben in a fault-fold system has not sunk, but has been raised less than the horst, just as, in folded systems, the beds in the syncline have been raised less than those in the anticline. But as yet it has been possible to recognize outside of lateral pressure scarcely any force which could move a block system differentially upward.

THE PRESENT FORMS OF OCCURRENCE OF THE SALT MASSES OF THE GERMAN TERRANE

The outer form and inner structure of the salt masses are intimately related to one another, and in this relationship we recognize everywhere a more intense deformation of the salt than of the adjacent formations and cover. This effect without doubt is the result of the high plasticity of the salt. Even at normal temperature and normal pressure the salt has a relatively high plasticity, which increases extraordinarily with increasing pressure and increasing temperature, as has been shown experimentally by Milch (19) in regard to the temperature and by F. Rinne (20, 21) in regard to pressure.

The following three main types can be distinguished among the various forms of the German salt deposits:

a) Salt beds (*Salztafeln*)
b) Salt anticlines (*Salzsättel*)
c) Salt stocks (*Salzstöcke*)

Salt beds.—The salt beds (see Fig. 3*a*) are horizontally lying or gently inclined platelike masses of salt formations regularly intercalated between the middle Zechstein below and the Bunstandstein above. Within the salt beds the individual strata in general are regularly concordant with one another and with the overlying and underlying formations; yet abundant irregularities and folds are met with which are not present in the overlying and underlying strata. Even overturned folds projecting far out, with salt strata thinning and thickening, are encountered in many places in the salt beds; such phenomena are all the more surprising in view of the great regularity of the bedding of the overlying Buntsandstein. The "salt beds" are present south of the Harz (south Harz area) and west of the Thuringian Forest (Werra area).

Salt anticlines.—The salt anticlines (Fig. 3*b*) are up-archings which have affected the salt and the overlying beds in somewhat the same degree, so that the salt is the core of an anticlinally folded complex of Buntsandstein beds. Although there are many types of special complications (21, Tafel 11), the bedding within the salt mass in general is anticlinal. If the salt core of the anticline has approached the surface and has come in contact with the ground water, a "salt table" (see below) is developed at the top of the salt core as the result of subsurface solution of the salt (Fig. 3*c*). As a result of such solution, the overlying beds sink and in certain areas of middle Hannover, the Tertiary is found preserved in "solution-grabens" above the salt, while off the salt, where the downward movement did not take place, it has been more or less completely removed by denudation.

Salt stocks.—It is in the German salt stock that the American geologist is especially interested, for in the first place the salt stocks are very similar in their general appearance to the salt domes of Texas and Louisiana, and in the second place oil is found in many places on their flank zones, as in Texas and Louisiana (Wietze-

Steinförde, Hänigsen, Oelheim). Their genesis has been the most disputed question of all the German salt occurrences. They show special peculiarities as to: (1) their outer form and especially their position with reference to the adjacent formations, and (2) their inner structure.

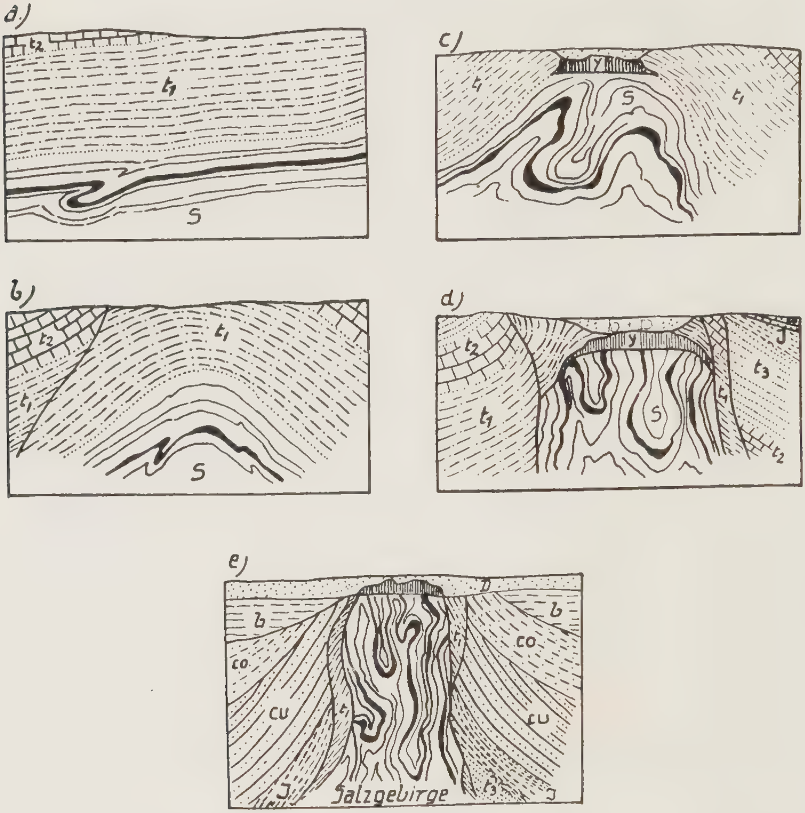

FIG. 3.—Tectonic forms of the occurrence of the German salt deposits: (*a*) "salt bed," south of the Harz; (*b*) salt anticline, South Hannover; (*c*) salt anticlines with "salt table," Hildesheim; (*d*) transition between salt anticline and salt stock, Benthe; (*e*) salt stock, North Hannover. Stratigraphic legend: *D*, Diluvium; *b*, Tertiary; *CO*, Upper Cretaceous; *J*, Jurassic; t_3, Upper Triassic (Keuper); t_2, Middle Triassic (Muschelkalk); t_1 Lower Triassic (Buntsandstein); *Y*, Residual gypsum cap; *S*, Salt formations with potash beds in heavy black lines; *CU*, Lower Cretaceous

The salt stocks are salt masses of circular, elliptical, elongated, or quite irregular plan, rising from great depths where in general they still have their roots. They no longer stand in the normal relation to their original cover, the Buntsandstein, but usually have penetrated into far younger beds, as for example into Cretaceous and Tertiary formations. Triassic and Jurassic beds are lacking on the salt stocks in extreme cases or are present as intermediate blocks between the salt and the younger adjacent formations. The salt is cut off above by a salt table (6) which is a more or less flat plane, formed by subsurface solution. The salt table in Hannover, the classic land of the salt stock, lies at a depth of around one hundred to two hundred meters (29). It is covered by residual gypsum (gyp cap), which is a residual formation resulting from the anhydrite originally held in the now dissolved salt.

The flanks of the salt stocks are in general extremely steep, but in many cases have gentle dips to great depths. It is observed in many cases that the flank of the salt stock bends in a "swan's neck" curve, and in a few cases this curve is present on all sides, so that the salt constricts in funnel shape downward; in extreme cases the salt stock may terminate in a point downward and stand as a great isolated salt drop floating in younger formations.

The inner structure of these salt stocks has become known in detail through potash-mining. In general, intensive folding is revealed, often of the isoclinal type, which expresses itself in a multiple repetition of salt beds in the same profile (see Fig. 4). In that folding, the single beds undergo mechanical thickening and thinning such as we know in the Alpine types of folding; such phenomena are most easily recognized through the potash beds; in the limbs of many folds, these show supernormal thicknesses, although in other places they have thinned until they are unworkable. Thus in the Riedel shaft (north Hannover), a series of salt beds which normally possess a thickness of sixty meters is only two meters thick in places, yet each individual bed is discernible though proportionately thinned (28). In rock salt which shows "yearly rings" (*Jahresringe*) with a greater or lesser content of anhydrite, Seidl (25, 26) has differentiated "compression salt" (*Stausalz*) and "tension salt" (*Zerrsalz*). In the compression salt, the yearly rings have separated from one another, while on the contrary in the tension salt they have approached one another, since the salt has been very greatly squeezed. The salt formations of the Zechstein in fact comprise beds of varying plasticity; carnallite is less plastic than the rock salt (21), and least plastic of all is the anhydrite, which occurs in thin beds as well as in the "main" anhydrite, with a thickness of forty to fifty meters. The "main" anhydrite,

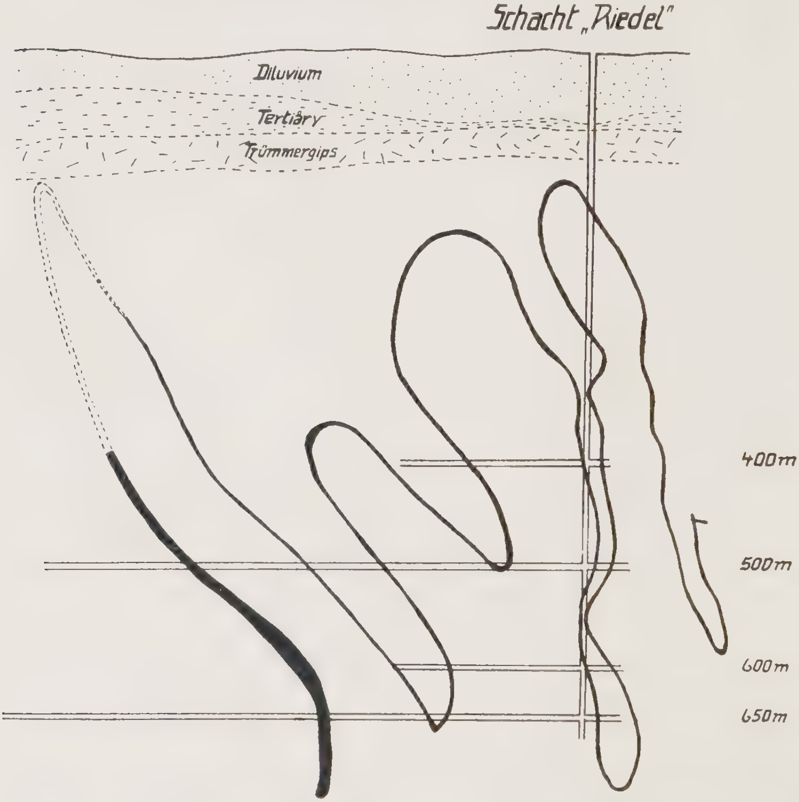

FIG. 4.—Section through the Riedel shaft (North Hannover), showing the folding of a single stratum in the potash salt beds.

(*Hauptanhydrit*) and in part also the "gray salt clay" (*Grauer salzton*) that accompanies it, show quite a different reaction to the tectonic forces from the rock salt and potash salt. The "main" anhydrite in most cases does not take part in the intensive folding, and does not deform plasticly like the salt, but in many cases is shattered. There arises therefore the form which has been designated by Seidl (25, 26) in correspondence with Mrazec as "diapir" folds, in which the more mobile salt wells up through the gaps in the "main" anhydrite.

Although the salt shows the typical phenomena of folded formations, the surrounding younger beds, everything considered, are displaced more after the type of block faulting.

THEORIES OF EXPLANATION OF THE UPTHRUST OF THE SALT

Atectonic upthrust of the salt masses.—The theory of upthrust of the salt independently of the normal tectonic forces has been advocated in Germany especially by R. Lachmann (12–18). The peculiarity of the phenomena which have just been described in their larger phases led him to the conception that any explanation through the normal theories of tectonics is not possible and that in the upward movement and deformation of the salt masses, therefore, quite other forces must have acted than those which deformed the adjacent rocks. He therefore spoke of an "autoplastic" upthrust of the salt masses, that is, an upthrust of the salt by forces which are located substantially in the salt. He had an idea especially of a molecular movement of dissolved material from zones of strong pressure to zones of lesser pressure, that is, from the great depths toward the surface. Through such processes of solution and recrystallization, the salt was supposed to have broken through the earth's crust as an ulcer breaks through the skin of an animal; hence Lachmann's designation, "salt eczeme." Lachmann did a very great service in having aroused discussion over many questions of the occurrence of the salt, but his theory lacked a satisfactory physical explanation for the assumed autoplasticity of the salt masses.

Isostatic upthrust of the salt masses.—Although isostasy has been awarded in Europe, and especially in Germany, only a secondary significance as the cause of the present structural relations of sedimentary beds, it has enjoyed more common acceptance as the cause of salt upthrust. E. Harbort (8–10) especially recognized the motive force for at least a part of the salt upthrust in the loading of the salt masses that already were present in a strongly plastic condition at great depth, and that therefore were already capable of being upthrust. According to Harbort, who did not misunderstand the position of the salt masses in the cores of the anticlines in the province of Saxony, in the sub-Hercynian basin, in southern Hannover, etc., the upward movement and the folding of the salt in the older Saxon periods was a folding phenomenon which affected the salt masses more strongly than the less mobile adjacent formations; but according to him, the latest upward movements at least are to be explained through the loading of the deeply buried salt by the younger sedimentary masses and the subsequent passage of the salt upward along fractures after the manner of a magma. Prominent students of salt domes such as Beyschlag (4), Seidl (26), and to a certain extent also Rinne (23–24) share Harbort's conception. Lachmann also approaches very near to it in leaning toward Arrhenius' (2, 3) ideas. Interested in the salt dome problems by Lachmann, who hoped to get from him a physical explanation of the atectonic upthrust of the salt, Arrhenius attributed the upward movement of the salt mass to its lesser specific gravity, compared with that of the normal rocks. He seems to have assumed that the salt stocks in general are surrounded by wet soft clay or even by ground water.

Upthrust of the salt masses through folding.—The chief exponent of the conception that in the upward movement of the salt the same forces have been active as in the adjacent formations, that is, in last analysis, lateral compression acting in the earth's depths, is the author (27, 29–31). In this theory, the cause of the peculiarities of the tectonic forms of the salt masses lies exclusively in the peculiarities of the materials in question. It is not that different forces have acted in the salt and in the adjacent formations, but rather that the same forces have worked differently, and they have worked differently because of the different character of the materials.

THE INTERPRETATION OF THE SALT UPTHRUST IN THE FRAME OF THE SAXON STRUCTURE AS A WHOLE

Everything considered, the theory of atectonic change of form of the salt formations can be regarded as overthrown. In opposition to one another there remain therefore to be evaluated the theories of isostatic upthrust and upthrust through folding.

The continuity of the forms of occurrence of the German salt deposits.

—Unquestionably one main error has repeatedly been made in the investigations and discussions of the German salt bodies, that is, that to account satisfactorily for a single object or a single type will solve a problem which in the last analysis must find its explanation in the consideration of the totality of the phenomena. Scientific controversy in Germany turned in the main around the salt stocks ("salt pillars," "salt eczemes"), although there is a certain agreement to the effect that the salt *anticlines* were the result of the lateral pressure that had affected the other rocks of the German terrane. But one may not regard the salt stocks apart from the other occurrences of the salt, especially the salt anticlines. The salt stocks are connected with the salt anticlines: (1) as types of phenomena; (2) in space.

The connection as types of phenomena consists of a complete series of intermediate forms between the typical salt anticline and the typical salt stock, not only in regard to position in reference to the adjacent formations, but also as to the yet more complicated inner structure (see Fig. 3). Certainly an anticline as we find it at Salzderhelden, in south Hannover, where the salt shows no great special complications in its inner structure and where it is regularly covered and mantled by the older Triassic as the core of an anticline, is immensely different from a typical salt stock of the Lüneburg type, where a huge pillar of salt sticks up in the middle of Cretaceous and Tertiary beds, even lacking, in some cases, the intermediate beds of Triassic and Jurassic, and where there prevails a folded structure which is comparable to the Alpine types of folding. But between these two there stand other forms, anticlines in which the salt core has experienced a somewhat intensified upward movement so that perhaps it is mantled in some parts by Buntsandstein but in other parts by much younger beds, in which, however, the anticlinal character is visible both in the inner structure as well as in the anticlinal structure of the adjacent formations. Such intermediate forms are met, for example, east and west of the city of Hannover. The series of the forms of the salt bodies can be begun with the flat salt beds, which can be thought of as derived from salt anticlines by the decrease of the dip of the wings, such a series, from the salt bed through the salt anticline to the salt stock, is represented in Figure 3.

If these natural relationships had been kept more sharply in view, much misdirected effort in working out the tectonics of the salt deposits would have been avoided.

With regard to their connection in space: the three main types of salt occurrences are somewhat separated in their geographical relations; the flat salt beds are found in general in those areas where the downward movement came to an end in the early Jurassic and in which therefore the salt sank only a relatively small distance. These areas have experienced only slight post-Variscan deformation in connection with the relatively slight post-Variscan sedimentation.

The salt stocks are confined to the areas of stronger post-Variscan sinking and sedimentation, that is, especially the North German basin.

The salt anticlines are found in their characteristic form in the transition areas, therefore in the areas of medium sinking and sedimentation.

Certain zones of uplift can be traced from the peripheral areas far into the North German basin (35); *and with the advance into the latter, along one and the same line of uplift, the form of the anticline goes over more and more into the form of the salt stock.*

The time relations of the upthrust of the salt.—Of decisive importance for the significance of a salt upthrust are its time relations compared with the time relations of the other Saxon tectonics. In both cases time relations are ascertained through the help of angular unconformities, and it is to be said that in general the same series transgress over and around the salt formation which transgress discordantly elsewhere in the Saxon area. From those relations as well as from the massive sedimentation in the intervals between the periods of deformation of the salt formations, it follows that the salt beds participated in the above-described upward and downward movement of the Saxon fault-folding in the alternation of orogenic and epirogenic processes, and that they participated in a far stronger degree in the upward movement than the non-saline formations; the author illustrated this in a diagram published some time ago which showed only four periods of orogenic upward movement, but newer investigations now indicate that the number of the periods is much greater. To the transient character and periodicity of the folding and of the upward movement of the salt masses, an exception is to be taken farther on, but if this exception is disregarded, it follows (27) *that the salt has been folded and has been moved upward in the same orogenic periods which are recognizable elsewhere as the periods of folding in the German terrane.*

The salt stock as the extreme form of an anticlinal core.—The position of the salt in the core of an anticline is very clear in the case of a salt anticline; the clarity, however, decreases with the transition to the salt stocks, and in individual extreme cases of salt stocks, the anticlinal position is perhaps no longer recognizable; but, as we have seen, salt stocks are tied together by transition of form and transition in space with salt anticlines, so that both must be explained in the same way. They fall, moreover, into the same periods of formation, if again we neglect the exception previously mentioned. The salt stocks, in last analysis, are the extreme form of anticlinal cores, in which the anticline is modified to unrecognizability; they are anticlinal cores that have advanced far ahead of the anticlinal wings and in the process have undergone an extensive change of form.

The rounded horizontal plan of many of the salt stocks does not contradict the conception of the salt as an anticlinal core; comparable forms, the so-called (structural) domes, are known also in Saxon structures of non-saline formations, and in fact they occur in many cases as the result of the summation of effects at the intersection of two axes of uplifts (see above). Thus it can be recognized that in many places in north Hannover the salt stocks lie at the intersection of the lines of uplift of Hercynian and Rhenish direction (29). In general, as in the Saxon tectonics, a substantial rôle is played by interference phenomena in determining the distribution and form of the salt bodies.

It appears therefore from (1) the recognizability of the occurrence of the salt as anticlinal cores or as derived from such through intermediate forms and through gradation in space, and (2) the contemporaneity of the upthrust of the salt with the periods of the Saxon folding, that it is not pertinent to call on other forces for the folding and uplift of the salt than those which folded and uplifted the non-saline beds of the German terrane.

The thesis is untenable and as yet has never been seriously advocated that in salt anticlines the lateral formations have come into their present position through folding, while the salt has come into its present position in the anticlinal cores and has been deformed in general by other forces. If the salt anticlines have arisen under the same compression which, acting upon the earth crust, led to the Saxon folding, the same theory of origin should be valid also for the salt stocks, which are traceable from the salt anticlines in all degrees of transition. That the upward movement was far stronger and the inner deformation far more intensive than in the non-saline beds is explained by the extraordinary capacity of the material for deformation. By "inharmonious" folding the author understands the quantitatively and qualitatively unlike reaction of different rock masses of the same section to mountain-building forces. Thus schists fold much more intensively than the overlying quartzites and in many cases force themselves injectively into the gaps in the quartzite masses. The salt tectonics are nothing other than an extreme form of inharmonious folding (31). In Figure 5, in case (*a*) it is assumed that the beds from *a* to *l*, including beds *c* and *f*, have reacted harmoniously to the folding force, and thus a normal anticline arose, cut by a few faults. In contrast to this, in case (*b*), bed *c* is assumed to be highly mobile (salt) and bed *f* is assumed as more strongly mobile. When bed *c* is strongly compressed it advances far ahead of the overlying beds and bed *f* is disturbed in an increased degree next to the salt.

By the advocates of the theory of the autoplastic upthrust of the salt, it is assumed that the formations underlying the salt (middle Zechstein) are not involved in the upward movement and folding which affected the salt. Borings and exposures in shafts show the opposite; but that the more stable underlying formations are far less affected than the much-disturbed salt is quite in accordance with the picture of inharmonious folding.

THE SALT UPTHRUST AS AN INTERMEDIATE FORM BETWEEN NORMAL TECTONICS AND VULCANISM

Harbort, Rinne, and others have compared the upthrust of the salt with eruptive processes, since they assumed the cause of the upthrust to be the weight of the overlying sediment; but under the explanation of the upthrust of the salt through lateral compression, the comparison with the upwelling of magmas still stands, so that in this sense the salt upthrust is "injective folding" (31). Salt tectonics therefore fill a gap in "normal tectonics," that is, between the tectonics of rocks of normal mobility and the tectonics of vulcanism, if we except from the latter the explosion phenomena developed by gas pressure, that is, if we take vulcanism especially in the sense of the deep-seated vulcanism (34). In recent times in Germany, Hans

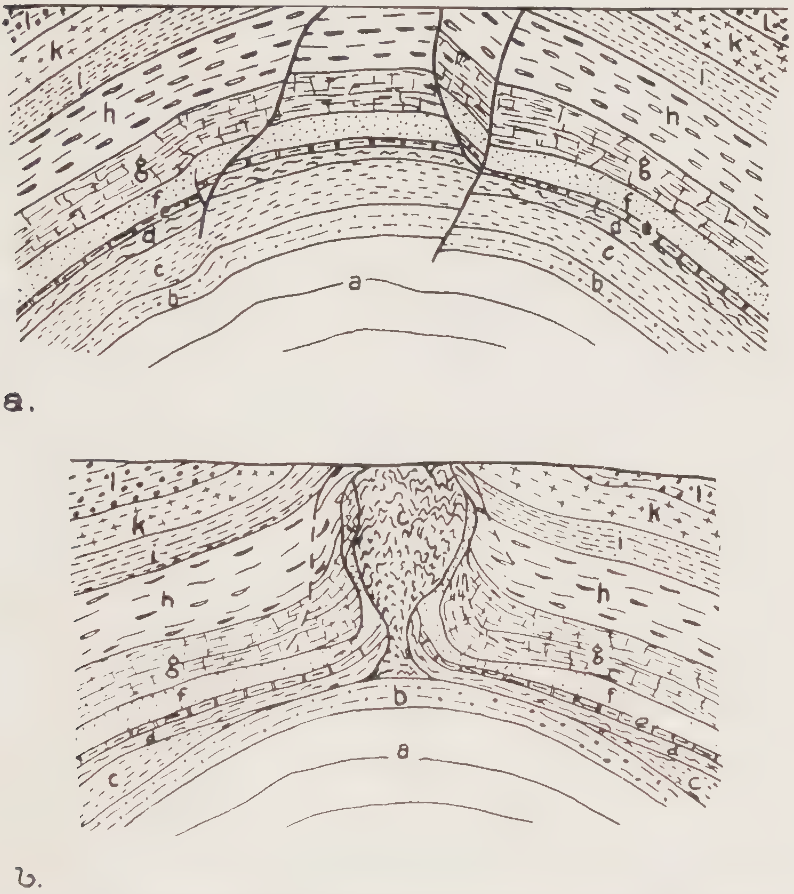

FIG. 5.—Diagrammatic sketch showing the relation of the form of folding to the mobility of the rocks.

Cloos, starting from the micro-structure of the plutonic rocks, has advocated tectonic thrust as the cause of the rise of magma and its penetration into the beds of the earth's crust in the form of laccoliths; he has spoken of vulcanism as "the tectonics of highly mobile materials." Vulcanism, of course, is differentiated from the orogenesis of normal rocks in that it is not only tied up with the orogenic periods of the past, but in that it also occurs outside of those periods in times which in the structure of the normal rocks are characterized as exclusively epeirogenic. Not only the strong forces which are at work in orogenesis but also even the far weaker ones which call forth epeirogenesis, therefore, are capable of setting magma into movement on account of its high mobility. Salt in this regard is intermediate between the normal rock and the magma. If it was said previously that the folding and upward movement of the salt were confined to the well-known orogenic periods of Mesozoic and Cenozoic tectonics, the salt appears also exceptionally to have been highly disturbed once outside of these periods. Gripp (7) thinks he recognizes such an exception in one region in which the salt formations feeding the salt rock sank very deep and therefore were especially mobile. With that exception, the law of the time relations of orogenesis, that is, that orogenesis is confined to very definite periods of the earth's history which possess more or less world-wide significance, is valid for normal tectonics. Its validity for vulcanism, on the contrary, if we accept vulcanism as tectonic in Cloos' sense, is incomplete for although orogenic times are in general periods of increased vulcanism, yet vulcanism can take place outside those periods. For salt formations, also, the law of the time relation of orogenesis holds only with restrictions. As was expressed by Rinne, magma and salt, as mobile materials, as masses with very high capacity for deformation, react to tectonic forces far earlier than the rigid rocks (24).

The salt structure and even its extreme form, the salt stock, become understandable as structures of uncommonly mobile masses. The highly peculiar phenomena shown by the salt structures are sufficiently explained thereby and need not mislead us into postulating for their formation forces other than those which have given the non-saline beds their tectonic forms.

F. Rinne, the Leipzig scholar to whom we are indebted not only for long years of investigation into the geology of German salt deposits, but also for his researches, holds the periodicity of the processes, of deformation, in the sense of the law of the time relation of orogenesis, as valid for the non-saline rock and considers it natural that plastic masses intercalated in those rocks should participate in temporary processes of folding and should hasten ahead of the adjacent formations. At the same time, according to him, the salt stocks can be brought into upward movement by the weight of the overlying beds. The fact of the covering of the salt by transgressive series, and in fact by the same series that appear transgressively quite generally in the Saxon terrane, finds an explanation in the fact that such series barred the way to the uprising of the salt in shattered territory, as the result of the weight of the overlying beds. But as the deformation in the adjacent formations, which are cut off equally by the transgressive series, is older than the transgression, the much more pertinent assumption is that the salt had experienced upward movement before the transgression, together with the adjacent formations; that is, that the transgression series was laid down on the salt, and not conversely that the salt was gradually pushed up to the transgressive series. Rinne asserts especially that mountain-building, salt upthrust, and magma intrusion lead back to a single fundamental motive force, gravity. But does not the unity of this motive force remain protected if salt upthrust and intrusion of magma are brought into connection with the phenomena of folding? for this also in the last analysis finds its cause in gravity. The salt upthrust in this sense, is not an immediate but an indirect effect of gravity, for the tectonic forces active in the earth's crust arise first of all from gravity, and these forces cause the salt to move upward.

In Arrhenius' hypothesis, the upthrust of the salt as a result of its lesser specific gravity depends on the direct effect of the gravitative field. But in this case the comparison with magmatic upthrust fails; the uprising masses of magma in many cases are heavier than those through which they are being forced. If we wish to speak of magma upthrust as tectonic here, it is surely only the increased mobility which is the cause of the increased movement. There is a contradiction in the fact that on one side the upthrust of the salt is compared with the upthrust of magma, and on the other side the upthrust is to be explained through the lesser specific gravity of the salt.

CONCLUSION

If the formation of the German salt anticlines is attributed to the same compressive thrust which has affected the beds above and below the salt formation, then, if one does not wish to separate things which quite evidently and naturally belong together, orogenic thrust must be recognized as the cause of the upthrust and of the inner change of form of the salt stocks as well. That the salt stocks project as folded formations into the middle of block-faulted masses of adjacent beds and of the cover, that the salt has therefore been more intensively deformed than the adjacent beds, and that, coincidently with its heightened inner deformation, it has advanced in the general deformation far ahead of the non-saline adjacent formations, is explained sufficiently by its higher mobility. This is merely a special case of general experience that the form to which orogenesis leads is principally a function of the mobility of the material in question (33). In this sense, the salt stocks illustrate the extreme case of inharmonious folding.

Thus the author conceives the upthrust of the salt less as the ejection of an especially *light* material than as that of an especially *mobile* material. In this sense, there is agreement with the upthrust of magma, which in so many cases is heavier than the beds which it penetrates.

Against the explanation of the upthrust of the salt isostatically through the weight of the overlying cover, there is the connection of the movement of the salt with the periods of Saxon orogenesis. The fact that quite exceptionally salt bodies appear once to have been moved upward outside of these periods may be explained by the fact that the salt, as a rock of very highly increased capacity for deformation, reacts to lesser tectonic forces that could effect no deformation in the normal rocks. Thus the movement of the salt fills a gap between the tectonics of deformation of normal periods, and the upward movement of magma which occurs so often outside such periods.

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DISCUSSION

D. C. Barton: Stille's views have been severely questioned recently by Franz Schuh[1] in the three papers in *Kali.* The following is a digest of a rather detailed review by Brinkmeier of the papers.[2]

Schuh discusses the two fundamental theories of mountain-building, contraction, and isostasy, and, accepting the latter, is enabled to regard compression and tension as co-ordinate, while advocates of the contraction theory have to regard tension and uplift as subordinate to compression. In a critical discussion of Stille's views of the later Mesozoic (Saxon) mountain-building in Germany, he attempts to show that at the beginning of the folding in the Cimmerian period," a tectonic frame (*Rahmen*) in Stille's sense was not present, and, rejecting Stille's "injective folding," advocates the view that the Cimmerian and early Senonian folding belongs in two completely different dynamic periods; i.e., that the first indicates a period of tangential tension, and that the second indicates a period of tangential compression in a southwest-northeast direction; that is, in contrast to Stille's belief in "fault-folding" repeated in every tectonic period, he regards the separation of the faulting from the folding as necessary and possible.

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[1] "Beitrag zur Tektonik unserer Salzstöcke," *Kali,* Heft 1; "Die saxonische Gebirgsbildung," I, II, *Kali,* Heft 8; "Salztektonik," *Kali,* Heft 17, 18.

[2] *Zeitschrift für angewandte Geophysik,* I (1923), Heft 3, pp. 86–89.

The essence of the author's views, in regard to salt dome tectonics, is that the salt stocks correspond genetically to the graben of normal tectonics; that the areas of depression (*Senkungsfeld*) on either side of the salt stock correspond to horsts which remained standing, and between which the graben sank, and that salt stocks, as well as grabens, go back in their origin to tension faults. On the ground of these assertions, for which no real evidence is brought forward, the views of Stille in regard to the special connection of horsts, normal anticlines, and anticlinal swells (*Breitsättel*) on the one side, and shallow synclines (*Breitmulde*), synclines, and grabens on the other, are regarded as erroneous. Stille's explanation of the formation of these various structures from the character of the deep-lying Variscan basement is rejected as resting on mechanically impossible conceptions, while the effect of the massive cover is recognized only in Harbort's and Seidl's sense. The conception of the Cimmerian period as a period of tangential tension is combined in the explanation of the upward movement of the salt forces.

After contrasting the opposing views of Lachmann, Stille, and Harbort, Schuh accepts Harbort's conceptions, as expressed by Seidl in his "Notes on the Theory of Genesis of the Permian Salt Deposits in Middle Germany": i.e., that the upward flowage of the salt masses is brought about originally by tectonic causes, and takes place along zones of dislocation, and that the concomitant squeezing out of the salt under the flat-lying blocks on either side results in a sinking of the center of each block and a tilting up of its edges. On the assumptions (1) that the salt formation is overlain by a massive cover several kilometers thick; (2) that after a period of faulting following tangential tension there follows a longer period of relative tectonic quiet, and then a period of tangential compression in a northeasterly direction; and (3) that the cover yields easily, but does not fracture, he attempts to show experimentally that such special features arise as gentle archings between the fracture zones, movement of the plastic material (salt) to the fracture zones, rupturing of the less plastic beds, piercing and upward bending of the edges of the cover.

The type of the form of the salt stock, according to Schuh, depends on the varying types of combination of fracture systems, i.e., he predicates "intersection of fractures" in contrast to Stille's "intersection of axes" and "axial nodes."

The tangential compression in the later periods, he believes, causes a decrease in the width of the salt stock and forces it up, and causes the formation of an anticline in the prolongation of the salt stock, if the fracture through which the salt has risen is perpendicular to the direction of thrust. If, however, the fracture runs parallel to the direction of thrust, this late tangential compression causes the broadening and cross-folding of the salt stock and the formation of a broad arch.

On the basis of the published data, he discusses the tectonics of many of the German salt domes, and, according to the reviewer, rather tries to bend the published descriptions of the structure to his previously conceived theories in a way that would probably not be acceptable to most of the respective authors. Although known in a few cases, the tectonics of the basement underlying the salt deposit remains unconsidered by Schuh.

Brinkmeier's verdict regarding the paper is that Schuh fails to prove his point, and instead of presenting definite evidence, reiterates mere assertions. He believes, however, that even if it is not possible to agree with the author's arguments, yet that they may present suggestive points of view for future work.

THE AMERICAN SALT-DOME PROBLEMS IN THE LIGHT OF THE ROUMANIAN AND GERMAN SALT DOMES

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ABSTRACT

The American salt-dome problems are divisible into two parallel series, the one comprising problems of description, the other problems of theory. The solution of the latter are of necessity dependent upon solution of the former. The American salt domes consist of subcircular stocklike masses of salt, capped in most cases by limestone and gypsum-anhydrite, intruded into and surrounded by Pleistocene-Eocene or Eocene-Cretaceous sediments which dip quaquaversally away from the salt core. The domes show certain tendencies to alignment. They occur in regions of geologic quiescence where there has been no compressive folding.

The Roumanian salt domes are divisible into two groups, the Carpathian–Sub-Carpathian, and the Transylvanian. The Carpathian–Sub-Carpathian domes consist of narrow, elongated, vertical intrusions of the Salifere salt, clays, and marls along anticlinal axes and into a thick series of Pliocene and Miocene sediments. The domes occur on the edge of, and immediately in front of, the Carpathian sheet overthrust and are aligned along structural, mostly anticlinal, axes which reflect the effect of the Carpathian tectonics. If the difference in the structural setting is allowed for, the Roumanian domes closely resemble those in America. Their origin has usually been attributed to some phase of the tangential thrust of the Carpathian mountain-building forces. Krejci recently has raised strong objection to that theory, and has advanced a tectonic-isostatic theory according to which tectonic thrust is responsible for the localization and initiation of their formation, but the weight of the overlying sediments is responsible for the upthrust of the Salifere core. The Transylvanian domes occur in the Plio-Miocene Transylvanian basin. Although only poorly known, they seem to be very similar in form to the American domes. They are aligned on anticlinal axes which are subparallel to the periphery of the basin.

The German salt domes are a phase of the German salt deposits, which are a definitely sedimentary series with a well-defined, persistent, and characteristic section. One of the middle members carries marine fossils, and two members are potash bearing. On account of the extensive mining and exploration for this potash, and on account of the recognizable section in the salt series, the structural deformation of the salt deposits has been worked out in great detail. On the basis of form and structure of the salt deposits there is a complete gradation in type and in space from undeformed sedimentary beds through broad anticlines with slightly swollen cores of salt (Strassfurt type), sharp anticlines where the salt core is starting to pierce the cover (Asse type), to broken anticlines in which the salt core has been squeezed up between the two flanks (Leine type), or to salt stocks (Hannoverian type) in which a pluglike mass of salt has been intruded for thousands of meters vertically into the overlying sediments. There seemingly can be no dispute that the German salt domes and salt ridges are the result of the plastic deformation and flow of a sedimentary salt series. The salt domes and ridges are aligned along Rhenish and Hercynian anticlinal axes. Many of the domes seem to be at the intersection of axes. The upthrust of the salt cores is attributed to tectonic thrust by Stille, who presents substantial evidence for such a theory. Lachman, Arrhenius, Seidl, and others argue less conclusively for an isostatic upthrust.

In view of the evidence of the Roumanian and German salt domes, in addition to

what is known about the American domes, it would seem unreasonable to believe that the American salt domes are not the result of the plastic deformation and upthrust of a sedimentary salt series.

INTRODUCTION

The purpose of this paper is briefly to review the more salient features of the present-day knowledge of the German and the Roumanian salt domes, in order to point out the lessons which that knowledge may offer in regard to the problems of our American salt domes. This paper follows the line of earlier papers by Rogers and Van der Gracht. Since the time of those papers there has been a very great addition to literature available in regard to the German salt domes. The data on the German, Roumanian, and Transylvanian domes were obtained from a brief visit to the German and Roumanian domes, from oral discussions with Stille, Mrazec, Böckh, and Papp, and from papers listed in the bibliography at the end of this paper. A list of the published sheets of the *German Geological Survey*, on which salt domes occur, is also appended.

THE AMERICAN SALT DOMES

The American salt domes consist of pluglike masses of very pure rock salt, capped in most cases by limestone, gypsum, and anhydrite. These plugs occur in and cut through the unconsolidated sands and clays of the Pleistocene, Pliocene, Miocene, Oligocene, and Eocene in one case, and Eocene and Cretaceous in the other, and they are surrounded by beds dipping quaquaversally away from the salt core.

The salt core is very nearly circular in plan, has a relatively flat top, and very steeply sloping sides. In general, it tends to conform in profile to one of the three types shown in Figure 1. In only a very few cases does the salt overhang at all, and in those cases only slightly. The salt cores range in diameter from $\frac{1}{2}$ mile to 2 miles (1 to $3\frac{1}{2}$ km.), and the depth to the top of the salt ranges from 15 feet to more than 2,000 feet (3 to 600+m.). The salt is known from three mines and various cores from wells. It is uniformly clear and granular, colorless, and very pure NaCl, except in faintly dark bands which are reported to contain scattered small crystals of anhydrite. Potash is known only in a single core from a depth of 4,800 feet in the Rycade Oil Corporation Gray No. 1 at Markham. The potash is present chiefly as sylvite. The salt of this core also contains algae.

The cap rock consists of a disklike mass of rock resting on the salt table, in a few cases extending slightly down the flanks of the salt core, and possibly in a few cases wedging out into the flank sediments. The cap rock in most cases consists of uniform, even-grained, rather homogeneous anhydrite or of well-crystallized selenite with cleavage faces some centimeters or even decimeters in diameter. The gypsum has apparently resulted from the alteration of the anhydrite. The cap in many cases is partly composed of limestone or dolomitic limestone. The limestone tends to cap the anhydrite-gypsum cap, but in some cases is reported to be found within the main body of the anhydrite-gypsum mass. Some of the Louisiana domes have a thick cap composed chiefly of limestone. The cap ranges in thickness up to 1,000 feet (300 m.). Many of the domes, as, for example, many of those in central southern Louisiana, have no cap rock at all; the Sulphur, Louisiana, dome, at the other extreme, has a cap slightly over 1,000 feet thick. The cap rock averages, on the whole, around 300 to 400 feet (100 m.) in thickness. Native sulphur is found to some extent as a secondary constituent of the cap rock of many domes and, in a few cases, in very considerable quantities.

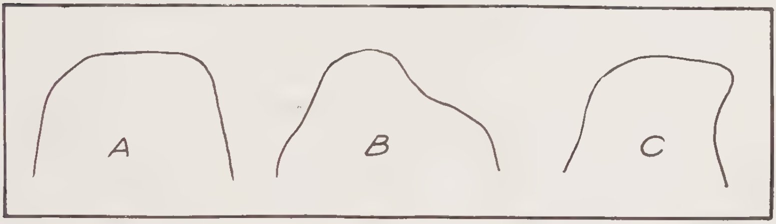

FIG. 1.—Three main types of profiles of American salt domes. *A* = Pine Prairie, *B* = New Iberia, *C* = Vinton.

The American salt domes are found in every case to cut across unconsolidated, or only slightly consolidated, sedimentary formations. They occur in three groups: a coastal group, all of which lie within 150 miles (250 km.) of the coast, a group in northern Louisiana, and a group in central east Texas. The coastal group of domes occurs in a region where the unconsolidated sands and clays of the Tertiary are over 6,000 feet (2,000 m.) thick, and these domes are known to cut formations of all periods from the Claiborne (Eocene) to Recent. Beds earlier than Claiborne in age have not been identified as yet in the wells on and around these domes. The two interior groups of domes occur in regions of Upper Cretaceous and of Eocene formations, and the salt domes cut Cretaceous and Eocene formations.

All the American salt domes occur in regions of geologic quiescence, where the beds have not been subjected to lateral folding movements and show only regional dip or gentle warping. Around the salt domes, however, there is marked deformation of the beds. At many of the interior domes, such as West Point and Keechi, the beds exposed at the surface can be seen dipping steeply away from the center of the dome, and beds whose normal stratigraphic level is several thousand feet below the surface have been brought to the surface. Wherever it has been possible to draw subsurface cross-sections across the coastal domes, the same marked dips away from the salt core have been revealed. On the deeper beds at Damon Mound the dip amounts to around 45 degrees, even out as far as half a mile from the edge of the salt. The dips around many dome seem to be much gentler than at Damon Mound. The upper beds may extend clear across above the top of the salt, and in that case show only gentle warping. With increasing depth, the dip of the beds becomes increasingly greater. According to the subsurface work of the geologists of the Shreveport office of the Amerada Petroleum Corporation, the presence of salt domes with marked uplift of surrounding beds is not shown in the regional-structure contour maps of northern Louisiana.

The areal arrangement of the Gulf salt domes is shown in Plate 2. The interior Texas domes lie either on an elliptic arc or on a faintly curved line parallel to the Balcones fault and on a crossline. The interior Louisiana domes do not fall distinctly on any lines. Of the coastal group of domes, those in southeast Texas show a general tendency to fall on lines trending NNE.–SSW. and bending slightly SW. toward their southern extremities. There is also a suggestion of NW.–SE. crosslines, but very possibly the alignment of the domes along these lines is entirely accidental. The five domes in south Texas lie on a NNW.–SSE. line. In southern Louisiana the alignment is much more obvious; the Five Islands form a well-marked line, convex toward the southwest, and striking NW.–SE.; Anse la Butte and New Iberia are on a parallel line; there is also the well-marked E.–W. line on which fall five salt domes and two oil fields not known to be salt domes.

The problems of the American salt domes, as the writer sees them, are listed in Table I. Although seemingly somewhat exhaustive, the list is far from complete. Detailed attention to an analysis of each of the problems will in most cases reveal a very considerable number of subordinate problems or phases of the main problem which have not been listed. A dual division of the problems has been made into what can be called (*a*) problems of description and (*b*) problems of theory. The "problems of description" deal essentially with questions of fact in regard to the actual physical makeup of the American salt domes—questions which can be solved by observation and description. The "problems of theory" deal with the questions of interpretation of these facts to the end that we may explain the method of formation of such actual physical structures as we find the American salt domes to be.

The problems of theory are of necessity dependent upon the solution of the respective problems of description. Series of alternative hypotheses can be advanced a priori, but the probability of the various theories can be evaluated only with the solution of the problems of description. A very large part of the discussions by American geologists of those problems of theory is invalidated because of the fact that the discussions were based on inadequate solution of those problems of description, or upon an inadequate grasp of what was known in regard to the solution of those problems.

TABLE I

Outline of American Salt-Dome Problems

Problems of Decription	Problems of Theory
A. Physiography I. Descriptive classification of salt-dome mounds II. Relation of surface to subsurface III. Relation of mounds to physiography of surrounding region	I. Cause of the deformation resulting in the formation of salt-dome mounds *a*) of simple, convex mounds *b*) Of secondary and subsidiary mounds *c*) Of central depressions II. Age of the salt-dome mounds
B. Structure of salt dome—descriptive classification of salt domes in regard to: I. Salt core *a*) Form of salt mass (1) Top (2) Flanks (3) Bottom *b*) Composition and petrography of salt mass *c*) Structure of salt mass	I. Source of the salt II. Method of *mise-en-place* III. Mechanics of *mise-en-place* IV. Age of the salt
II. Cap *a*) Composition of the cap *b*) Petrography of the cap *c*) Paragenetic relations of the different members of the cap *d*) Form of cap (1) Position and relation to salt core (2) Position and relation to super-salt-sediments (3) Position and relation to flank beds *e*) Structure of cap	I. Origin of the cap *a*) Anhydrite-gypsum (1) Source of the anhydrite-gypsum (2) Reactions and conditions resulting in deposition of $CaSo_4 \pm 2H_2O$ or in alteration of limestone to $CaSo_4 \pm 2H_2O$, if the anhydrite-gypsum is secondary *b*) Limestone (1) Source of the limestone (2) Reaction and conditions resulting in its deposition, if it is secondary *c*) Sulphur (1) Source of sulphur (2) Reactions resulting in its deposition
III. Surrounding sediments *a*) Supersalt beds (1) Structure (2) Petrography	II. Age of the cap (especially in reference to age of salt and of salt dome)

TABLE I—*Continued*

Problems of Description	Problems of Theory
(3) Stratigraphy	III. Relation, if any, of the cap to the Oligocene limestone
(4) Age	
b) Flank beds	I. Cause of thinning of section and of thinning of some beds above the salt
(1) Stratigraphic section	
(*a*) Normal section away from salt domes	II. Historical geology of salt domes *a*) At the beginning of upthrust
(*b*) Section near dome	*b*) Periods of maximum movements vs. periods of relative quiescence
(2) Structure of flanks	
(*a*) General	*c*) End of the movement
(*b*) Faults	*d*) Amount of upthrust that took place in each period
(*c*) Unconformities	
(*d*) Relation of flank beds to salt core	III. Reason for predominance (?) of sand near salt core
(3) Petrography	IV. Reason for calcareous (?) cementation of sands near salt core
(*a*) Near the salt	
(*b*) Out from the salt	V. Cause of any such variation (if any) in ratio sand to clay
c) Surface	VI. Cause of any such variation (if any) in SO_4, Cl, $CaCO_3$, and sulphides
(1) Variation of ratio sand to clay on and off salt dome	
(2) Variation in SO_4, Cl, $CaCO_3$, and sulphides in soils on and off salt domes	
C. Regional relations of the salt domes	I. Regional forces and conditions which result in salt-dome activity
I. Tectonic-orographic framework of the general region in which the salt domes occur	II. Localization of salt domes
II. Alignment of the salt domes	
III. Relation of salt-dome lines to the tectonic-orographic frame in which they occur	
IV. Relation type of dome to position, in the tectonic-orographic frame and to thickness and character of setting	

TABLE I—*Continued*

Problems of Description	Problems of Theory
D. Salt-dome waters I. Composition and concentration in reference to depth and stratigraphic horizon, for normal Gulf Coast waters II. Variation of salt-dome waters *a*) With proximity to dome *b*) With depth *c*) In cap	I. Cause of any variation *a*) Source of materials in solution *b*) Reactions
E. Mineralogy of the salt domes	I. Source of the materials II. Reactions resulting in the formation of the minerals
F. Salt-dome geothermal temperatures and gradients I. Variation with depth II. Variation in relation to oil-and-water relations III. Variation with proximity to dome IV. Areal variation around dome V. Variation with regard to age of oil field	I. Cause of high temperature and gradient in cap rock II. Cause of low gradient in flank III. Cause of areal variation of gradient IV. Cause of high temperature (if so) of water than of oil
G. Petroleum and natural gas I. Descriptive classification of kinds of oil on Gulf Coast II. Composition of various oils III. Modes of occurrence IV. Regional occurrence of oil V. Regional occurrence of natural gas VI. Stratigraphic relations of natural gas VII. Stratigraphic relations of oil VIII. Variation of character and gravity with depth, stratigraphic horizon, and dome IX. Oil-production figures *a*) Total production per dome	I. Source of sources of the oil II. *Mise-en-place* of the oil III. Reason for extreme differentiation of the oil on some domes IV. Age of oil and of oil deposits V. Why are some domes productive, others barren?

TABLE I—*Continued*

Problems of Description	Problems of Theory
b) Per acreage production per dome	
c) Productivity in relation to horizon	
d) Productivity of individual wells	
e) Productivity with different types of spacing	
H. Volcanic theory of origin of salt dome I. Evidences of volcanism in Gulf Coast II. Evidences of solfataric action in Gulf Coast III. Association of any such evidence of volcanism or solfataric action with salt domes of Gulf Coast	I. Method by which volcanic activity could produce salt domes II. Possible connection in time and space of salt-dome activity with volcanic activity
I. Ascending brine or gas theories of the origin of salt domes I. Evidence of ascending brine solutions of any amount in salt-dome area *a*) Present brine springs *b*) Evidence of subsurface brine circulation of sufficient amount II. Evidence of amount of gas escaping from domes III. Evidence that faulting or anything else could imitate an upward current of water or gas in any considerable amount upward through many thousand feet of gumbos and sands IV. Evidence that any such movement of brine or gas could maintain itself V. Evidence (*a*) that growing salt crystals is of order to	I. Method by which a salt deposit of the type of the salt domes could be formed from ascending brine solutions or by escaping gas II. Why would not ascending solutions be diluted instead of concentrated? III. Why would not deposit be in form of a stockwork of salt veins ramifying through sediments?

TABLE I—*Continued*

Problems of Description	Problems of Theory
account for doming; (*b*) evidence of such growth in character of salt crystals	
J. Tectonic theories	
I. Evidence of plasticity of rock salt sufficient to allow flowage	
II. Evidence of movement by recrystallization under pressure	
III. Force of lateral compression	I. Would not friction at sides of rising core counterbalance the possible lack of density?
a) Evidence of presence of lateral compression in general region	
b) Evidence of association of salt domes with such lateral compression	
c) Evidence in structure of salt dome of lateral compression	
IV. Isostatic forces	
a) Amount of compensation around salt domes	
b) Mass of salt core vs. mass of surrounding sediments	
K. Geophysical relations of salt domes	I. Probable reserves of petroleum, sulphur, salt, potash, gypsum
L. Economic importance of salt domes	

The papers of the present symposium in large part deal with the problems of description, and offer a wealth of information in regard to the American salt domes. But when the broader outlines of this wealth have become evident, it will be seen that knowledge of our American salt domes is woefully scanty and inadequate. We have fairly detailed, but in no way complete, knowledge of the outer form of the upper part of the salt core, in the case of a very few domes, of the cap, and in the case of the rest, only scattered bits of knowledge. We have fair information in regard to the structural relations of the sedimentary beds in the more recently discovered oil fields, and some knowledge concerning the structure of the upper beds in the interior groups of domes. But we have very scanty information in regard to the salt core, which, indeed, is the core of the problem. In the absence of adequate solution of the problems of description of the salt core, we shall be unable to come to any decision between the possible a priori solutions of the problems of theory. In virtue of the large potash mines, and of the extensive exploration for potash in Germany, the German geologists have been able to come to a far more adequate solution of the problems of description and theory than we have in the case of any of the problems concerning our American domes, and they also have been able to come to as adequate a solution of the problems of sedimentary structure as have we. The solution of the problems of description of the Roumanian domes has not gone as far on the whole as in the case of the American domes, but as conditions in the two areas are different, the fragmentary knowledge obtained from Roumanian sources helps to throw light on the solution of the problems of the American domes.

ROUMANIAN SALT DOMES

In Roumania salt domes occur (*a*) in the outer edge of the bow of the Carpathian Mountains and in the adjacent Sub-Carpathian zone, and (*b*) in the Transylvanian basin.

CARPATHIAN AND SUB-CARPATHIAN SALT DOMES

The broad features of the geology of the region in which the first group of salt domes occur are as follows: The Carpathian Mountain system, bending in a sweeping arc from Galicia southward into the center of Roumania and then westward, is composed of (*a*) an "island" of crystalline rocks at the northern end of the system, (*b*) an "island" of crystalline rocks composing the western third of the Roumanian Carpathians, and (*c*) the Flysch, Early Tertiary, zone (Fig. 2). The Carpathians are composed of folds, in many cases broken or overturned, and of gigantic overthrusts in which the active thrust has been outward.

From the Galician border southward, and then westward as far as the valley of Dambovitza River, the outer edge of the Carpathian

Mountain zone is bordered by the Sub-Carpathian Miocene zone. This zone is divisible into three subzones: (1) a northern Moldavian subzone, which is composed of open folds and separated by a fault from the Moldavian Plateau to the east; (2) a southern Moldavian zone extending as far south as the valley of Slanic River. This zone is characterized by crowded folds and is bordered by Sarmatic, Meotic, Pontic, and Levantinic, whose beds, thrown back at the contact with the Miocene, drop slowly to the Roumanian plain; and (3) the southern Carpathian subzone, extending from Slanic

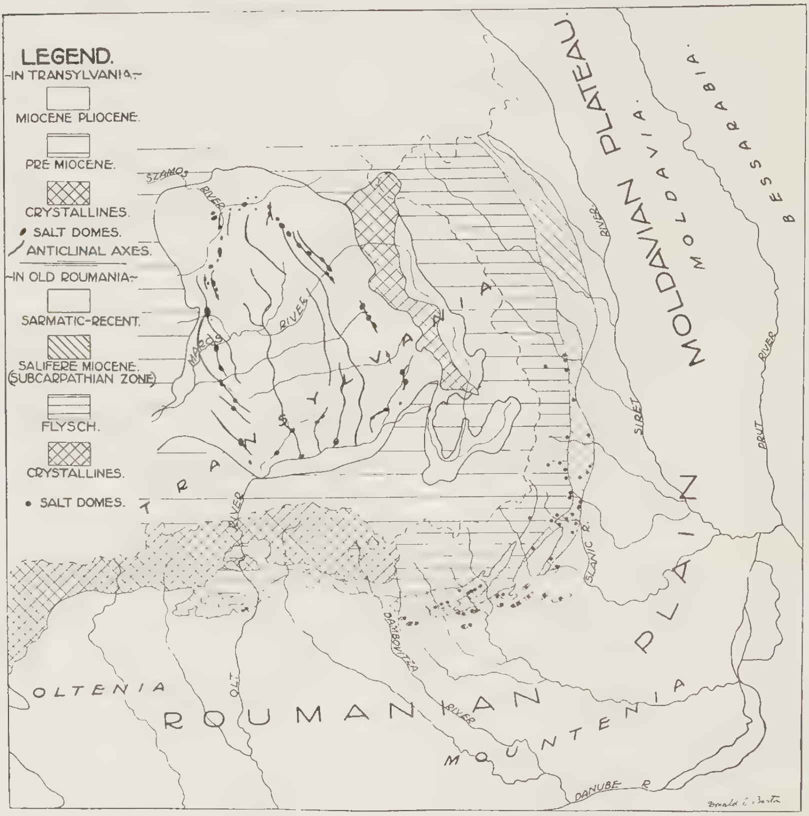

FIG. 2.—Geologic sketch map of Roumania showing the location of the Transylvanian, Carpathian, and Sub-Carpathian salt domes—after Mrazec, Papp, and Böckh.

River to Dambovitza River, and presenting a very complex structure. At the elbow of the Carpathian arc a bundle of folds diverge from the Carpathian curve and plunge to the southwest. The folds in the Miocene beds dip under Pliocene, which shows conformable but lesser folding, dying away to the southwest. An important structural feature of this zone is the Bay of Slanic, a tectonic bay of Miocene rocks extending back into the zone of the Flysch. This subzone is bordered by the Roumanian plain.

The salt domes of the first group are found indiscriminately in the second and third Sub-Carpathian zones, in the adjacent portion of the zone of the Flysch, and in addition, in two isolated domes west of Dambovitza River. In the second Sub-Carpathian subzone and the adjacent portion of the zone of the Flysch the salt domes are about equally distributed between the two zones and the distribution of the domes does not seem to show conformity in plan to the contact between the zones, unless possibly there is a tendency for domes of the zone of the Flysch to occur just within the outer margin of the zone. In the third Sub-Carpathian zone and adjacent portion of the zone of the Flysch the salt domes occur in the Sub-Carpathian zone but not in the zone of the Flysch. It is a notable fact that there are a great number of salt domes in the Miocene Bay of Slanic, and off the outer side of the Spur of Valeni, which is the Flysch tectonic peninsula inclosing the Bay of Slanic, but none on the spur itself. The number of the known salt domes in this first group of domes, according to Voitesti, is now well over seventy-five.

The salt domes are large, lenticular massifs of granular crystalline salt of a high degree of purity. The stratification of the salt is marked by alternating dark and light beds and by rare beds of argillaceous material, which in some cases contain the more-or-less carbonized débris of tree trunks. The salt, even including the "black" salt, has a NaCl content of 98.0 99.5 per cent.

The salt is merely part of the peculiar type of fold called by Mrazec "diapir" fold, or by Krejci "piercement" folds (*Durchspiessungsfalten*) and "outbreaks" (*Aufbrüche*). The characteristic feature of a diapir fold, according to Mrazec's definition, is that the beds of the core tend to pierce the overlying beds of the arch, and although laid down conformably, the beds of the core dip more steeply than the beds of the flank or roof. The piercement fold is the characteristic diapir fold in its earlier stages; the outbreak, in the later, extreme phase in which plastic, mobile sediments of the core have been intruded, mostly vertically, into the overlying sediments. The core in both the piercement folds and the outbreaks is composed predominantly of the marls of the Salifere (see Table II) and subordinately of salt, gypsum, sand, and sandstone. The salt seems to form the backbone of the outbreaks and apparently is present in relatively greater amount in the small outbreaks which come from great depth than the broader, more gentle ones coming from lesser depths.

TABLE II

STRATIGRAPHIC SECTION IN THE SUB-CARPATHIAN ZONE (AFTER KREJCI)

Age			Lithologic Character	Type of Deposits
Quaternary			Alluvium	Fluviatile and terrestrial
Pliocene	Levantic		Cross-bedded sand and gravel and marl	Fluviatile and littoral
	Dacic		Marls and sands	Littoral
	Pontic	Upper	Sand	Brackish water
		Middle and Lower	Marl	
	Meotic	Fresh-water Meotic	Sand and sandstone. Marl, sand, and calcareous sandstone, petroliferous	Littoral
		Dosinia horizon	Marl and calcareous sandstone, petroliferous	Brackish water
Miocene	Sarmatic	Upper	Missing	Terrestrial
		Middle	Limestone, calcareous sandstone, sand, and marl	Littoral
		Lower	Marl and calcareous sandstone	Brackish water
	Vindobonic	Salifere	Marl, sandstone, dacite tuff	Marine
	Burdigalic		Sand, marl, and conglomerate	Marine
Oligocene	Aquitanic		Clay, marl, gypsum, salt, and petroleum	Marine

The exact form of the diapir folds in Roumania is not well described in the literature. It is said by Krejci to be that of an ethmolith. In plan it seems to be a flattened ellipse, in some cases slightly crescent-shaped, with the convex side indifferently to the north or south. The outline of the Baicoi dome is a flattened ellipse several kilometers long and slightly over half a kilometer wide. The Ocnele-Mari dome is slightly more than 3 kilometers long by $\frac{1}{2}$ kilometer wide. In cross-section the core rises vertically from depths of 2,000 meters with relatively little change in width, tends in outline to approximate a logarithmic spiral, and in its upper part is overturned, predominately to the south, but at Gura-Ocnitzei and Baicoi toward the west and south, at Moreni toward both north and south, and at Floresti toward the north. Cross-sections of the Baicoi and the Moreni domes are given in Figures 3 and 4. If an outbreak does not reach to the surface it may be reflected in the surface beds by a normal structural dome.

Cap rock similar to the cap rock of the American and the German salt domes is not present. A thick mantle of tectonic breccia is described by Voitesti as characterizing the domes in the zone of the Flysch. The breccia is composed of large or small angular and rounded pieces of limestone, sandstone, marl, shale, crystalline schist, and eruptive rocks, in a matrix of argillaceous material. The tectonic character of most of the breccias is severely questioned by Krejci, who interprets them as surface formations.

The source of the salt is most commonly held by Roumanian geologists to be salt forma-

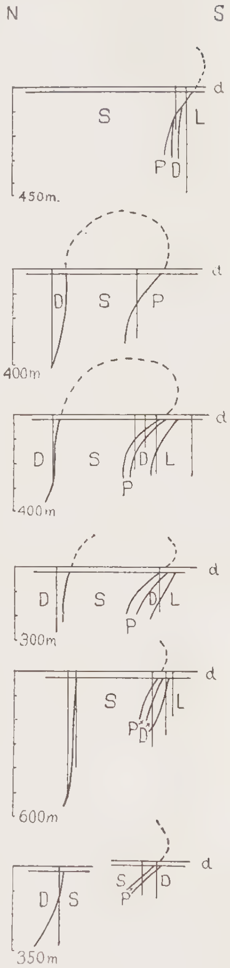

FIG. 3.—East-west series of north-south sections across the Baicoi dome. After Mrazec.

d=Diluvium,
L=Levantic (gravels, sands, and shaly sands) (*landesti* bed)
D=Dacian (*Vivipara bifarcinata* beds) (sands and marls)
P=Pontian (shaly marls and, in places, sand)
S=Salifere Miocene, gray marls and sandstones over a main salt core

tions in the Eocene-Oligocene or in the Miocene. As the salt cores in the zone of the Flysch cut all formations of the Flysch geosyncline, and in the sub-Carpathian zone formations from Jurassic to Quaternary, Voitesti believes that the salt is definitely older than Triassic and has formulated the theory that it is a pre-Cambrian chemical precipitate. On account of the overthrusting, however, it is not safe to predicate that the salt is older than all formations it pierces.

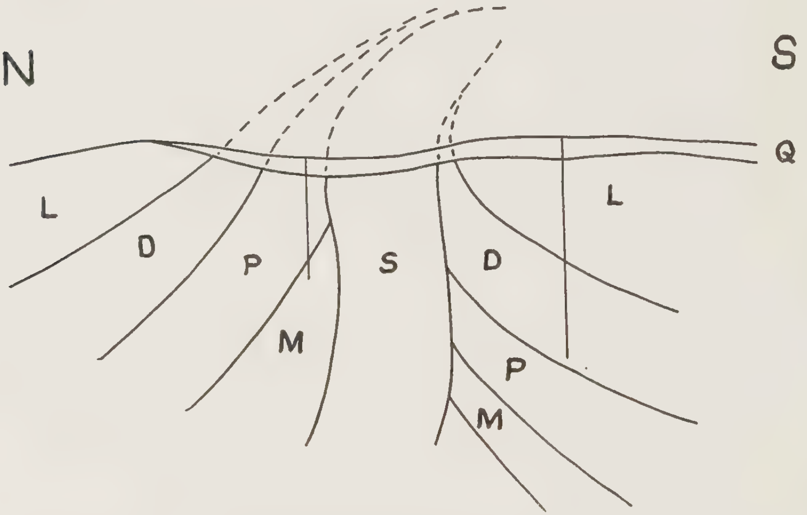

FIG. 4.—Section across the Moreni dome. After Voitesti. *Q*=Quaternary, *L*=Levantic, *D*=Dacic, *P*=Pontic, *M*=Meotic, *S*=Salifere.

On the flanks, the Meotic and Pontic either are present in narrow bands, steeply uplifted, or have been cut off in great depth against the thrust surface of the core, and the Dacic, or even the Levantic, lie directly against the Salifere. Commonly on the south flank the Meotic, Pontic, and Dacic, and in some cases the Levantic, are overturned toward the south.

The age of the uplift of the domes is Sarmatic to Levantic, according to Krejci. The uplift began in Sarmatic and Meotic times. Perhaps by Pontic, and at least by Dacic, times some of the outbreaks had been uplifted to such an extent that Dacic beds were deposited discordantly across their eroded crests. The main period of uplift began in upper Dacic times, and the Levantic beds were laid down transgressively across the steeply dipping beds of the older formations. As the Levantic itself is steeply uplifted or overturned in places, the movement continued until after the end of Levantic times, but as the diluvial stream terraces do not seem to be warped where they cross the outbreaks, the movement seems to have died out before Pleistocene times.

There is a definite tendency toward an alignment of domes along structural lines parallel to the front of the Carpathian overthrust (Fig. 2), and these structural lines apparently tend to be anticlinal axes. A great many salt domes occur within the Bay of Slanic which, according to the older interpretation, is a geosyncline, but they are on anticlinal lines.

The theories of origin of the Roumanian domes are mainly two: (1) the tectonic theory of Mrazec, which seems to have had rather general acceptance among Roumanian geologists until recently; and (2) the tectonic-isostatic theory recently advanced by Krejci. According to Mrazec a diapir fold represents the first stage of an overthrust. The diagrams in Figure 5 show his conception of the process: (*a*) by depression of the foreland a flexure is formed in which, as the result of the thrust of the foreland, there begins underthrust of the downthrown block of competent bed, II, against the upthrown block, I; (*b*) as the underthrust progresses, the understratum, III, is caught between I and II, and is forced up and partially over II, forming a diapir fold; (*c*) if the underthrusting is continued still farther, the piercing core of the substratum caught between I and II will be torn from its roots and will exist as an uprooted core or *klippe*, such as is believed to occur at certain points along the line of Tintea-Baicoi-Moreni. The thrust in the case of the Roumanian domes is interpreted as a phase of the tangential thrust which has caused the overthrusting in the Carpathians. Since the American domes are in a region of great geologic tranquility, where there has been no horizontal compressive thrust since far back into the geologic past, it is not possible rationally to postulate for the origin of American domes any compressive thrust sufficient to cause folding or overthrusting, and the writer long has thought that the Roumanian geologists were emphasizing too strongly genetic relationship between the origin of the Roumanian domes and the tectonic thrust from the Carpathian mountain-building forces.

Against the tectonic theory Krejci has raised the objections: (*a*) that although the mountain-building movements decreased from Sarmatic times on and had died out by Levantic times, the formation of the outbreaks did not begin until Sarmatic and Meotic times, reached its maximum in Dacic times, and continued with almost undiminished force into Levantic times; and (*b*) that although the intensity of folding within the Carpathians along the border of the southern Sub-Carpathian zone increases from east to west, the intensity of formation of the diapir folds decreases from east to west. Krejci postulates as a fundamental regional requisite for the formation of the Roumanian salt domes the presence of a

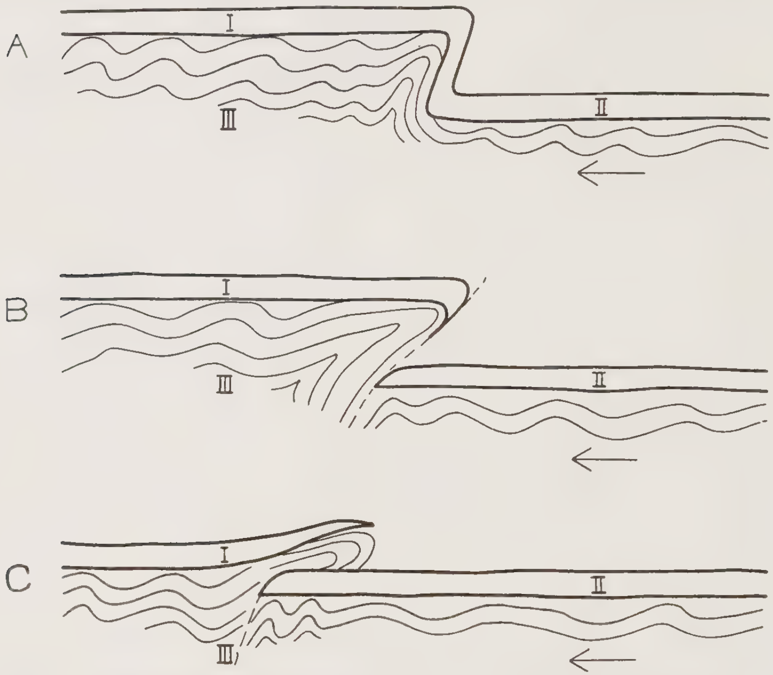

FIG. 5.—Diagrammatic explanation of the origin of diapir folds of the Sub-Carpathian type. After Mrazec.

formation composed of mobile plastic materials such as salt, clay, and marl, located at the front of an active sheet overthrust, and overlain by a competent cover which is neither too thick nor too thin and which transgresses at least to the edge of the overthrust sheet. He then conceives the formation of the outbreaks as taking place in three steps: (1) the formation of wavelike folds in the competent cover through the effects of thrust by the overthrust sheet; (2) the transformation of the folds into piercement folds through the yielding upward of the mobile plastic underlying formation under the effect of the same thrust, the upward movement being augmented at the points of least resistance along the crests of the folds; and (3) the transformation of the piercement folds into outbreaks through the extrusion of the plastic core vertically upward into the overlying sediments, the movement taking place isostatically under the effect of the pressure of the overlying sediments. Theoretically, the motive force in the final upthrust of the core could be tectonic thrust, but on account of the field evidence Krejci believes that tectonic thrust from the Carpathian mountain-building movements cannot have been the effective force, and therefore argues for upthrust due to the downward thrust of the sedimentary cover. The upthrust is made possible by the plasticity of the salt, clay, and marl, and by the lower specific gravity of the salt in comparison to the surrounding sediments, and it is aided by erosion of the crests of the anticlines with exposure of the plastic underlying formation and by deposition in the intervening synclines.

The Roumanian domes are not so well known as the American domes. They occur in a structurally complicated setting, and it is not easy to disentangle the salt-dome structure from the tectonic structure; furthermore, exploration has not gone so far as on the American domes. The Roumanian salt-dome geologist possibly may have more to learn from the American salt domes than the American salt-dome geologist has to learn from the Roumanian domes. The occurrence of the American domes in a region of tectonic quiescence suggests that tectonic thrust cannot have the importance postulated by Mrazec, and the characteristic relative excess of density of the upper part, at least, of the American salt core and cap, in comparison with the surrounding sediments, suggests that isostatic thrust is not competent by itself to explain the upthrust. The following features of the Roumanian domes, however, are suggestive in connection with the problems of the American salt domes: (*a*) the resemblance of the Roumanian domes to the American domes, if allowance is made for the effects of the complicated structural setting in which the Roumanian domes are found; (*b*) the occurrence of the domes in pronounced anticlines; (*c*) the occurrence of the salt and Salifere marls and clays as diapir-type cores in the anticlines; (*d*) the alignment of the anticlines along structural, chiefly anticlinal, lines; (*e*) the effective control of the structural setting on the form and occurrence of the domes.

TRANSYLVANIAN SALT DOMES

The Transylvanian group of salt domes occur in the Miocene-Pliocene basin inclosed within the bow of the Carpathian arc and the Apusen Mountains in the former Hungarian province of Transylvania, now ceded to Roumania. The Transylvanian basin consists of relatively flat-lying Miocene and Pliocene beds with a gentle regional dip to the center of the basin. The beds, however, are folded into a series of anticlines and synclines along axes tending to have a north-south strike, but also tending to conform somewhat to the edge of the basin. As the area is not known to be petroleum-bearing, and as there has been very little exploration for oil, little is known about the domes except the few in which salt mining is carried on. The known salt domes, as given by Papp, are shown on the map (Fig. 2). Inward from the edge of the basin there are other structural domes, some of which are suspected to be salt domes.

The data available in regard to the characteristics of the Transylvanian domes are scanty. The well-known Maros-Ujvar salt dome is elliptical in outline, with major and minor axes 2,700 and 1,500 feet, respectively. The salt core is said to have steep, or even slightly overturned, flanks, and the salt has dark banding which stands nearly vertical. At many of the domes, according to Papp, the flank beds have a quaquaversal dip away from the dome. In one case, according to a personal communication from Dr. Hugo Böckh, the dacite tuff can be traced with normal dip under the salt core. From the map (Fig. 2) it can be seen that the salt domes tend to occur on the anticlinal lines.

In the fragmentary state of knowledge of the Transylvanian salt domes there are only three points which are suggestive in connection with the problems of the American salt domes: (1) that the Maros-Ujvar dome resembles an American salt dome with its crest eroded; (2) that the salt domes tend to occur on anticlinal lines; and (3) that the salt domes occur in a region which has been subjected to moderate folding, but to no such thrust as the area of the Carpathian salt domes.

GERMAN SALT DOMES

The German salt domes are a phase of the North-German Zechstein salt deposits. These salt deposits were laid down in depressions of the basin which, in Zechstein times, extended from Netherlands on the west across Northern Germany into Poland on the east, and from Southern Denmark on the north to Munster, Frankfort-am-Main, Mamberg, Dresden, and Breslau on the south (Plate 3). Formerly, these salt deposits extended as a more-or-less continuous series of beds over wide areas, but by post-Permian tectonic movements the area in which they occur was broken up into several tectonic basins: the Magdeburg-Halberstadt basin, the Thuringia basin, and the Rhone basin. From the intervening areas of the Thüringerwald, Harz, and Flechtinger Höhenzug, the Zechstein beds have been eroded, but in the basins the salt deposits normally lie buried under the Triassic, Jurassic, and, in part, under the Cretaceous. To the north of these three basins the salt deposits in the Hannover area and in the area of the North German plain normally lie deeply buried under the Tertiary as well.

The salt deposits are composed of a series of formations that is very uniform over a wide area. The respective normal stratigraphic sections for the Werra district, the Middle Leine Valley district, the Stassfurt district, and the Hanover district are given in Table III.

According to the available literature, differentiation of the salt series in the Werra district into formations correlative with those of the standard Stassfurt series seems impossible, and the only formations which can be correlated between the Werra district and the other three districts are the overlying Upper Zechstein clays and the underlying Lower Zechstein. Throughout the other three areas the

TABLE III

STRATIGRAPHIC SECTIONS OF THE GERMAN SALT DEPOSITS

Werra District*	Normal Middle Leine Valley†	Normal Stassfurt‡	Normal Hannover§	Remarks
Upper Zechstein clays, 16–20 m.	Upper Zechstein clays, 20 m.	30 m. (20–30 m.)	0 m.	Massive red-clay bed with anhydrite nodules and a bed of anhydrite at the base
Dolomite, 15–25 m.	"Youngest" rock salt, 50–60 m.	30 m. (50)	30 m.	Rock salt
	"Pegmatite" anhydrite, 1–2.5 m.	1 m. (1–5)	1 m.	Anhydrite with scattered intergrown salt crystals and with a graphic texture somewhat like pegmatite
Lower Zechstein clays, 35–65 m.	"Red salt clay, 20–25 m.	10 m. (5–15 m.)	10 m.	Massive red clay with anhydrite nodules
			"Younger" salt, 60 m.	
			Younger sylvinite zone, 15 m.	
	"Younger" rock salt, 145–70 m.	50 m. (100–50 m.)	Kieserite zone, 10 m.	Rock salt with some polyhalite and anhydrite
			"Younger" salt, 70 m.	
	"Main" anhydrite, 20–40 m.	40 m. (40–90 m.)	40 m.	A massive bed of anhydrite without traces of bedding
Rock salt with two potash beds, 200–300 m.	"Gray salt clay," 4.5 m.	7 m. (4–10 m.)	7 m.	Clay, dolomitic marl, and anhydrite in places carrying marine fossils very widespread and very uniform
	"Older" potash beds, 8 m.	30 m. (30–40 m.)	30 m.	Fifty-five per cent carnallite (KCL-$MgCl_2$-$6H_2O$), 26 per cent rock salt, and 17 per cent Kieserite ($MgSO_4H_2O$), on the average
	Transition zone, 13 m.	10 m. (20–40 m.)	10 m.	Rock salt and kieserite
	"Older rock salt," 70 m.	250 m. (300–500 m.)	250 m.	Rock salt with anhydrite bands averaging 94 per cent rock salt and 6 per cent anhydrite and clay
Lower Zechstein	Lower beds not exposed	Lower 70–100 m., anhydrite	Lower beds not exposed	Anhydrite with intercalations of bituminous dolomitic beds and of one or two ten-to fifteen-meter beds of rock salt
		Zechstein, 4–10 m., limestone		
		Zechstein, 0.5–4 m., conglomerate		

* After Everding.

† After Renner.

‡ After Seidl.

§ Figures with parentheses after Everding (1907); without parentheses, after Seidl (1921).

normal section varies from district to district chiefly in the thickness of the individual members and in the presence in the Hanover district of a potash zone in the "younger rock salt" in addition to that at the top of the "older rock salt." The general lithologic character of each of the formations is remarkably constant, and the older rock salt and the younger rock salt are sufficiently different in petrographic character, so that they can be distinguished from one another readily. This differentiation of the German salt series has been of the utmost importance in studying the German salt domes, for by means of it the German geologists have been able to work out with great precision the enormously complicated internal structure of the salt domes.

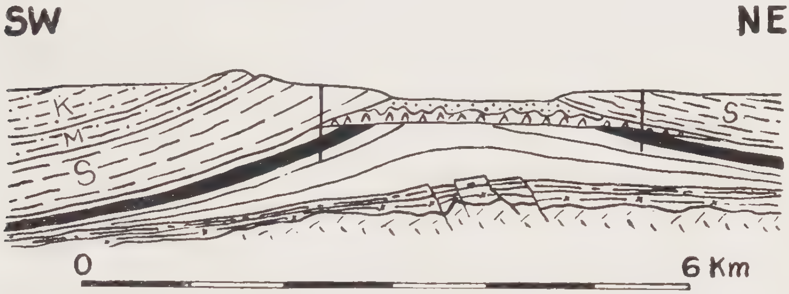

Fig. 6.—Section across the northwest end of the Schmücke-Finne salt-dome ridge (example of Stassfurt type). After Schlafke.

The German Zechstein salt deposits occur in the following structural types:[1]

1. Normal, unaltered sedimentary beds, nowhere exposed
2. Sedimentary beds in essentially normal position but altered by
    - *a*) Squeezing out of the "Older rock salt" and less often of the younger rock salt in the synclinal areas between the salt ridges
    - *b*) Solution, at the outcrop of the Zechstein along the edge of the Paleozoic arches
3. Beds showing reduplication but still having the aspect of normally lying sediments
    - *a*) Werra, Fulda, South Harz districts
4. Salt domes
    - *a*) Stocklike salt domes
    - *b*) Salt-dome ridges

[1] Essentially after Seidl—Ref. 19.

On the basis of form and structure, the following types of salt domes and salt ridges can be recognized:

a) Stassfurt type (Fig. 6).
Broad anticlinal zones with broad cores of the older rock salt; the older potash beds occurring on the flatly dipping flanks; the crest of the salt core long since dissolved away; the salt core 700–1,000 meters (2,300–3,300 ft.) thick.

b) Asse type (Figs. 7 and 8).
Small, more fissure-like zones with scantily faulted salt deposits not completely piercing the overlying beds; the "Older beds" in places forming stock-like masses; the crest of the salt core only slightly eroded away; the salt core 1,300 meters (4,200 ft.) thick.

c) Leine type (Fig. 9):
A broken anticline with salt squeezed up between the two flanks.

d) Hannoverian type (Figs. 10 and 11):
Stocklike salt cores with complicated internal folding and flanked by strongly dragged, and in part overturned, lateral beds; the salt core 600–3,000 meters (2,000–10,000 ft.) thick. The Hanoverian type is very similar in general form to the American salt domes and differs from them chiefly in that there is usually one dimension longer than the others.

Like an American salt dome, the characteristic German salt dome, of any of the four types, is composed of a salt core, with a gypsum cap and with flank beds dipping away from the salt core.

The salt core, in a very large number of the salt domes, is well exposed in the workings and borings of the various potash mines. Detailed study of the salt formations forming the salt cores has therefore been possible and has shown the presence of the characteristic section which extends with relative constancy throughout the domes. By means of this section, and especially certain members of it which, although thin, are persistent in spite of folding, it has been possible to work out with great delicacy the very intricate folding which is present in many of the salt domes. Although the minor folding in the Stassfurt and Asse types may be complicated, the general pattern of the folding is of a relatively simple anticlinal type (Figs. 6, 7, and 8). The Leine Valley type is remarkably similar to case "C" in Mrazec's explanation of the formation of a diapir fold by under thrusting (see Figs. 4 and 9); and as postulated by him, the salt core has been rolled over, with a result, in this case of fairly complicated internal folding. The salt cores of the Hannove-

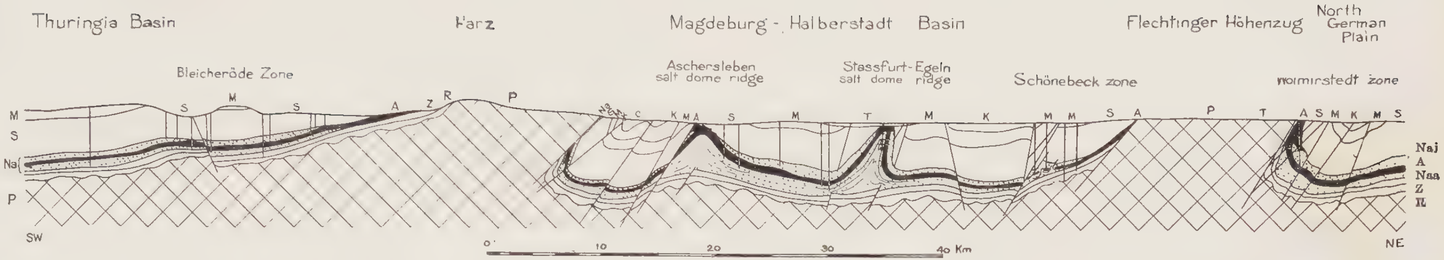

FIG. 7.—SW.-NE. structure section from the Thuringia basin across the Magdeburg-Halberstadt basin showing the structural relations of the Aschersleben and Stas furt-Egeln salt-dome ridges. (Partly after Everding and Geinecke; the Stassfurt-Egeln ridge modified after Schünemann; the Aschersleben ridge and Schönebeck zone after Seldi.)

T = Tertiary, *C* = Cretaceous, *K* = Keuper, *M* = Muschelkalk
S = Buntsandstein, *Na* = Zechstein salt series { *Naj* = "Younger" salt series; *A* = "Main" anhydrite; *Naa* = "Older" salt series }
Z = Middle and Lower Zechstein, *R* = Rotliegendes
P = Pre-Permian

rian type show a most complicated internal structure. The older salt seems to have broken through the apparently less plastic younger salt series, and in many places to have overturned and thrown it back. Figure 12 shows an example of the very complicated folding that has resulted. It should be noticed that the apparent anticlines of the section in reality are overturned synclines, and the apparent synclines, overturned anticlines. In the case of the Benthe salt dome, Stier has been able to map with great detail the folding shown by the salt and has been able to show the presence of two sets of folds, the one, Hercynian (NW.–SE.) in strikes; the other, Rhenish (NE.–SW.) in strike (Fig. 13). The effect of the Hercynian folding, furthermore, is stronger above the 600-meter level, and decreases with increasing depth, while the reverse is true of the Rhenish folding.

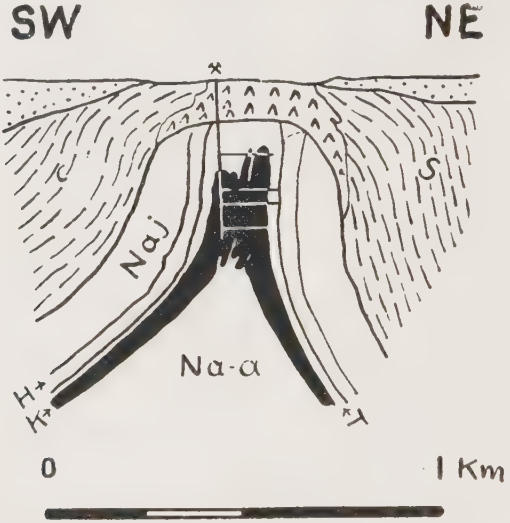

FIG. 8.—Section across the Stassfurt salt-dome ridge (at this point an example of the Asse type). After Schünemann. *S*=Buntsandstein, *Maj*="Younger" salt series, *H*="Main" anhydrite, *T*="Gray, salt" clay, *K*="Older" potash series, *Na-a*="Older" salt series.

The vertical thickness of the salt core, especially in the salt domes of the North German plains, is great. The following are depths at which wells stopped in the salt without having encountered

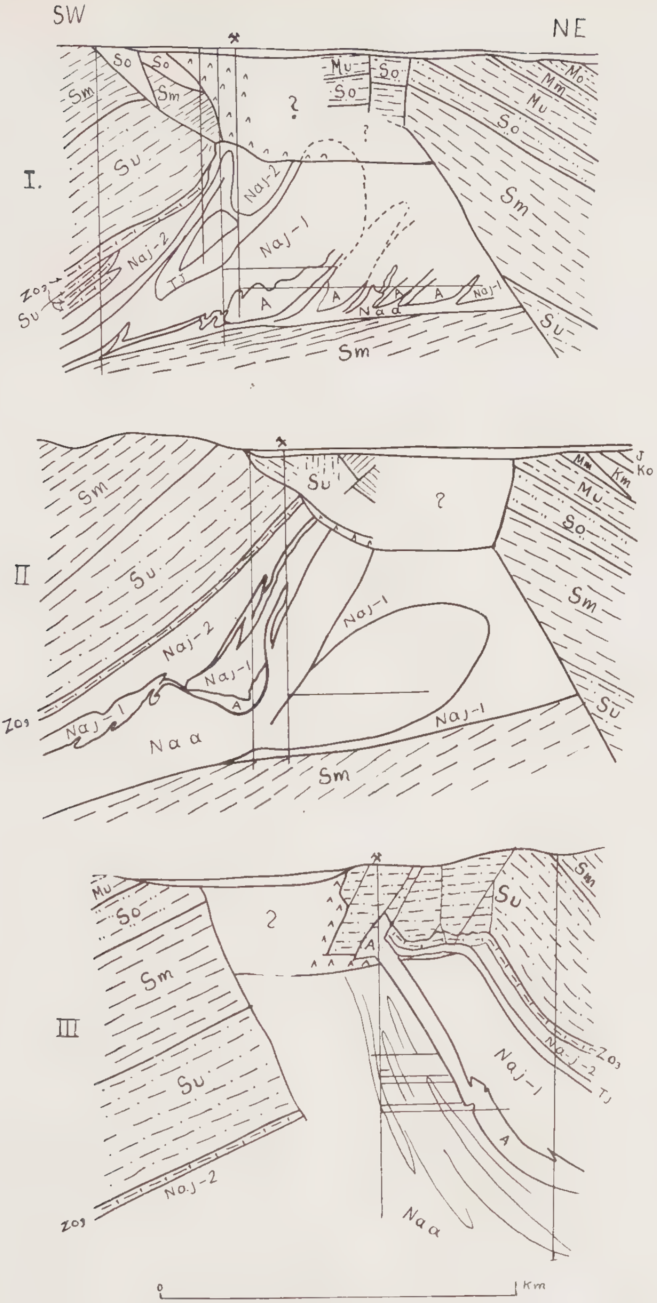

FIG. 9.—Sections across the Middle Leine Valley anticline near Alfeld. After Renner. Section I, 7.5 km. NW.; and section III, 11 km. SE. of section II.

Mo, Mm, Mu = Upper, Middle, Lower Muschelkalk
So, Sm, Su = Upper, Middle, Lower Buntsandstein
ZO_3 = Zechstein clays
Naj–2 = "Youngest" salt series
Tj = "Red-salt clay" and "Pegmatite" anhydrite
Naj–1 = "Younger" salt series
A = "Main" anhydrite
Na-a = "Older" salt series

the underlying formations: Hildesheimer Wald dome in the Northwest Harz foreland:

	Meters	Feet
Sülberg boring	1,350	(4,431)
Salzdetfurth No. II	1,400	(4,595)

SALT DOMES OF THE NORTH GERMAN PLAIN:

	Meters	Feet
Sperenberg	1,390	(4,562)
Salzwedel Boring No. IV Gustritz	1,408	(4,621)
Lubtheen	1,204	(3,952)
Altona, Lieth boring	1,338	(4,391)
Wietze-Steinförde Prinz Adelbert No. IV	1,613	(5,294)

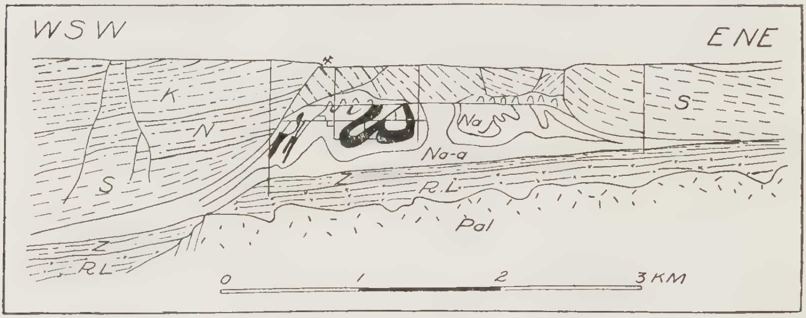

FIG. 10.—Section across the upper Aller salt-dome ridge (example of Hannoverian type salt-dome ridge). After Schmirrer and Seidl.

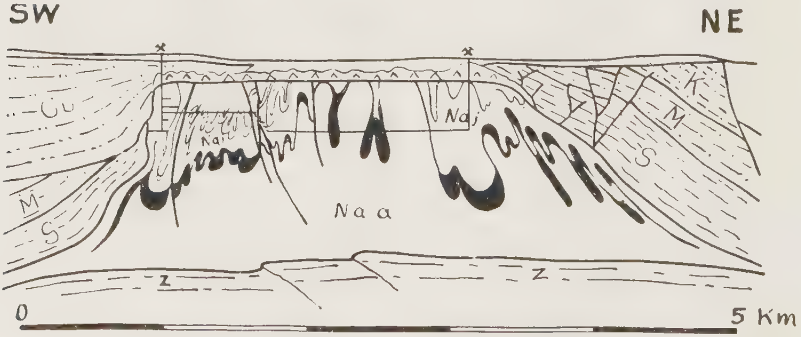

FIG. 11.—Section across the Benthe salt dome through the Deutschland and Ronnenberg mines. After Stille and Seidl. (Example of Hannoverian type salt stock.) *Cu*=Lower Cretaceous, *K*=Keuper, *M*=Muschelkalk, *S*=Buntsandstein *Na-j*="Younger" salt series, *Na-a*="Older" salt series, ∧ =gypsum cap

As the Prinz Adelbert encountered the salt at 109 meters, its record of salt from 323–5,294 feet surpasses the American record, made by the Texas Company at Humble, of salt from 1,340 to 4,400 feet (408–1,340 m.) in a well on top of the dome, and 2,342–5,410 ft. (713–1,648 m.) in a well on the flank.

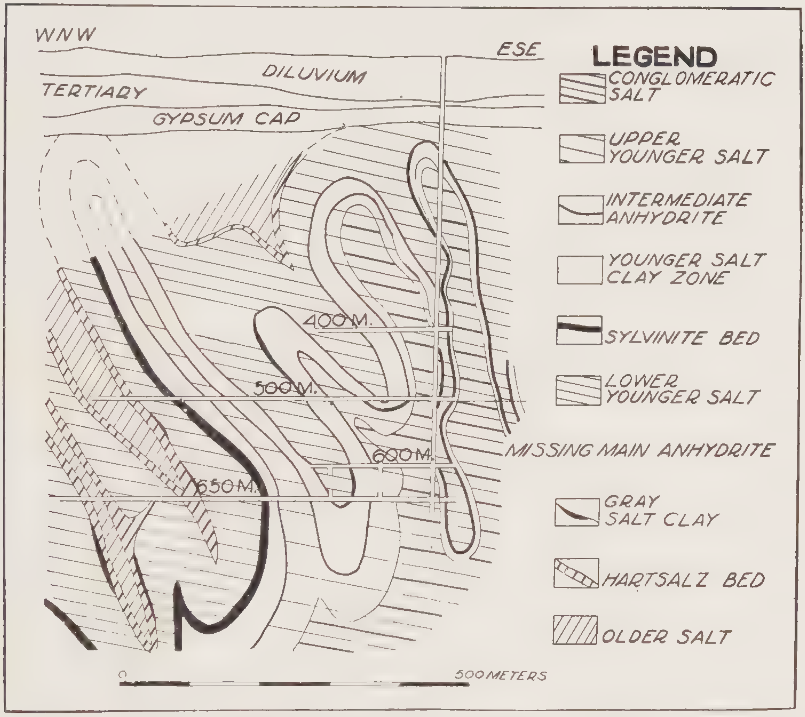

FIG. 12.—Section through the Riedel mine at Hänigsen, showing in detail the complicated folding of the salt series. After Stille.

One of the most striking features of this complicated folding is the extreme plasticity of the salt series as a whole, with, however, very great differences in the plasticity of the various members. The massive salt beds show a plastic reaction to deformation, while the "main anhydrite," the "gray salt clay," and the "red salt clay," show a rigid reaction: that is, under deformation, the plastic salt beds bend and stretch, while the rigid beds fracture and break. Where the folding is complicated, the main anhydrite and the gray salt clay commonly have been torn apart; in domes of the Stassfurt type they are found only in the synclines and flanks of the anticlines;

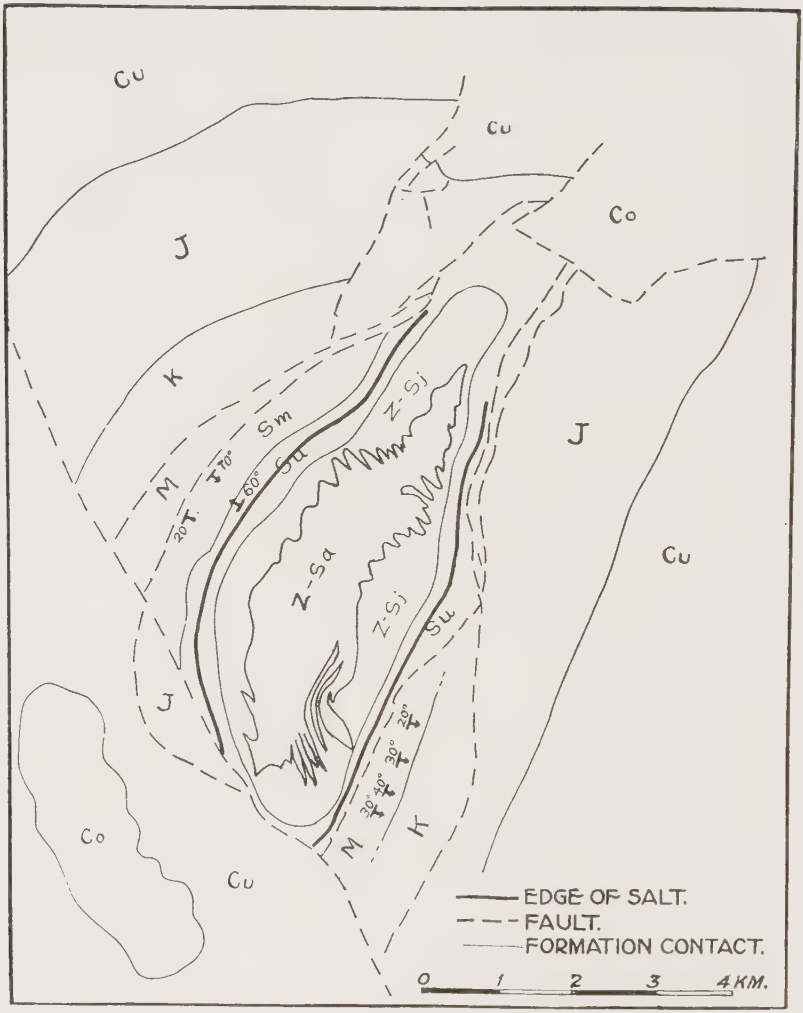

FIG. 13.—Sketch map of the Benthe salt stock. Surface geology after Stille—contact between *Z-Sj* and *Z-Sa* taken from 500-meter level in mines, after Stier. Quaternary and Tertiary cover omitted, *Co* = Senonian and Emscher (Upper Cretaceous), *Cu* = Marine Lower Cretaceous, *J* = Jurassic, *K* = Keuper, *M* = Muschelkalk, *Sm* = Middle Muschelkalk, *Su* = Lower Muschelkalk, *Z-Sj* = "Younger" salt series, *Z-Sa* = "Older" salt series.

and in the Hannoverian type of domes, they are found only in the troughs of the synclines and the crests of anticlines. Figure 12 shows an example of the extremely plastic reaction of the salt deformation.

The gypsum cap in a general way appears to resemble the cap of the American salt domes. It lies on the nearly level top of the salt core and has a thickness of a few centimeters up to 100 meters (0–300 ft.). The cap grades into a mantle that extends well down the flanks of the dome. The cap is composed predominantly of gypsum, in some cases mixed with clay or material from the overlying beds. In a few cases the base of the cap is composed of anhydrite rather than gypsum. The lower portion of the cap tends to have a fine, nearly horizontal, bedding, while the upper portion tends more toward a breccia. From the suite of specimens seen by the writer at the Technische Hochschule in Hannover, the gypsum and anhydrite of the cap of the German salt domes has a confused and irregular texture and lithologic structure that constrasts strongly with the even, uniform, coarsely crystallized selenite and the macroscopically massive, even, uniform saccharoidal anhydrite of the American domes. The origin of the cap rock in the German domes is attributed by the German geologists to regeneration and cementation of the residual anhydrite left behind in the solution of the top of the salt core. As can be seen from the discordant relation of the top of the salt to the folding, a very large amount of salt has been removed from the top of the salt core. As the salt contains a notable amount of anhydrite (the older rock salt, 5–6 per cent) in addition to the intercalated beds of anhydrite, the residual theory forms a perfectly plausible explanation of the gypsum cap of the German salt domes.

The flank beds dip away from the axis of the salt core as in the American domes, but there is considerably more of a tendency toward concordance between the flank beds and the edge of the salt core. The salt domes of the Stassfurt type and of the Asse type are not true diapir folds. The salt has arched up the overlying beds, or the salt and the overlying beds have been arched up together, but the salt core has not broken through them. Many of the salt domes of the Hannoverian type seem not to be diapir folds, but to have concordant relations between the flank beds and the edge of the salt core. In the case of many other of the domes of the Hannoverian type, as, for example, Wietze-Steinförde, Hänigsen-Wathlingen, Oelsburg (N. Peine), and probably Lübtheen and Salzwedel, the salt core is at least partially bounded by peripheral faults, cuts discordantly across the edge of the upturned flank beds, and stands in true diapir relation to them, similarly as in the case of the American salt domes of the Gulf Coast. The flanks of all the types are characterized by more or less faulting. The flanks of the following Hannoverian type of dome are overturned: Steinhuder Meer (SW. side), Hope Lindwedel (SW., NW., NE. sides), Benthe (NW. and S. sides), Sarstedt-Sehnde (NW. side), Sehnde-Lehrte (NNW. side), Fallersleben (W. side), Middle Leine Valley (W. side), South half, Upper Aller (NE. side), N. ½ Upper Aller (SW. side), Hohensalza (probably W. and E. sides).

Relations of transgression and angular unconformity are present in the flank and supersalt beds, and, according to Stille, folding has taken place as follows in the salt domes or in the salt-dome lines:

Pre-Cretaceous (Cimmerian) folding:

1. On the Rhenish-striking salt-dome line, Sehnde-Lehrte, Hänigsen-Höfer, Bardenhagen, Lüneburg
2. On the Hercynian-striking anticlines of the Calenberg and Asse axes

Intra-Cretaceous:

1. On the Rhenish-striking Hänigsen-Wathlingen dome.
2. On the Hercynian-striking Lower Aller salt-dome ridge

Early Tertiary:

1. On the Rhenish-striking Sehnde-Lehrte, Hänigsen-Wathlingen salt-dome line and the Benthe salt dome.
2. On the Hercynian-striking Lower Aller salt-dome ridge and Calenberg axis.

Late Tertiary:

1. On the Rhenish-striking salt domes, Hänigsen-Wathlingen, Bardenhagen-Kolkhagen, and Wünhow-Lüchow.
2. On the Hercynian salt-dome line north of Steinhuder Meer.

The type and character of the individual salt domes and the pattern of their arrangement reflect strikingly the setting in which the salt domes are found. The most important elements of this tectonic setting are: the Bohemian mass with its two tectonic Peninsulas of the Harz and the Flechtinger Höhenzug, the Hercynian system of fractures (NW. and W.–NW.–SE.) which characterize Central Germany and which control the form of the Harz and the Flechtinger Höhenzug, the Rhenish mass, and, to the north of the Bohemian and Rhenish masses, the North German plain, with its mass of sediments thickening northward.

Inclosed between the Harz and the Flechtinger Höhenzug is the tectonic Magdeburg-Halberstadt basin, which was formed by diastrophic movements in post-Permian times.

The tectonic pattern of the salt domes is what we should expect as a result of the collapse and slight lateral compression of such a basin, that is, a series of long anticlinal Hercynian axes conforming in direction to the sides of the basin. As the stratigraphic thickness of the overlying sediments above the salt formations in the basin was only 600 to 800 meters and was composed of relatively more consolidated sediments than the Tertiary rocks of the North German plain, the salt domes characteristically are of the Stassfurt and Asse types, in which the overlying beds have not been broken through by the salt, but have been arched with it.

In the North German plain, immediately off the front of the Harz and Flechtinger Höhenzug, the Hercynian (W.NW.–E.SE.) strike of the salt-dome axes of the Magdeburg-Halberstadt basin gives way to a predominately Rhenish strike (N.NE.–S.SW.). There are three well-marked Rhenish lines of salt domes: the Flackstöckheim, Theide, Rautheim, Fallersleben, Weyhausen line, the Oelsburg-Oelheim line, and the Sarstedt-Sehnde-Lehrte, Hänigsen-Wathlingen, Habighorst-Höfer line, in which the Sarstedt-Sehnde-Lehrte dome is itself a long narrow salt-dome ridge with a Rhenish strike. In addition, the isolated domes, Benthe, Didderse, Salzwedel, Kolkhagen, and Lübteen, show a Rhenish strike or traces of a Rhenish strike. It is as if the North German plain were being thrust against the northwest edge of the Bohemian mass, as marked by the line of the front of the Harz and the Flechlinger Höhenzug. In this zone of predominately Rhenish strike, however, the influence of Hercynian strike also is evident. Many of the salt domes seem to mark the intersection of a Rhenish line of uplift with the prolongation of one of the Hercynian lines from the Magdeburg-Halberstadt basin (Plate 3). In many of the domes, also, as, for example, Benthe (Fig. 13), the salt core shows the effects of both

Rhenish and Hercynian folding. In the case of the Benthe dome, the effects of the Hercynian folding are more pronounced above the 600-meter level, and the effects of the Rhenish become increasingly pronounced with increasing depth below the 600-meter level. According to Stier's interpretation, it is the Rhenish forces of folding which have provided the predominating motive force for the upthrust of the salt core.

The Hercynian lines again seem to control the alignment of the domes to the north and west of the Hanoverian area of predominately Rhenish strike. On the northeast there is the well-marked line of the Lower Aller, with both the Wietze-Steinförde dome and the Lower Aller (Verden-Kirchwahlingen) domes themselves showing a marked Hercynian strike, and there is also the Hercynian-striking Steinhuder Meer dome. To the north, there is the Lower Elbe group of domes, apparently forming an elongated area with a Hercynian strike. And it is in the prolongation of this zone that the two lone domes near Berlin occur. In the Lower Elbe salt-dome area it is possible to line up the individual salt domes along several possible salt-dome lines; as, for example, Helgoland, Stade, Winsen a.d. Elbe, Lüneburg, or Kolkhagen, Salzwedel, and Sperenberg, or the line Heide, Lieth, Altona, and possibly Lüneburg and Sperenberg, or the slightly less probable line, Segeburg, Lübteen, Conow, Wietze, and possibly Sperenberg. As was first suggested by Beyschlag and later emphasized by Stille, Seidl, and others, these domes probably reflect the prolongation of the series of folds which, in South Hannover, are exposed at the surface, but which in the North German plain are deeply buried under the Tertiary cover.

The cause of the upthrust of the German salt domes is attributed by the German geologists to tectonic forces. Stille, in his papers on the Hannover district and on injective folding, traces the pattern of the folding in the Hannover district and ties together the salt domes of the North German plain, the salt-dome ridges of South Hannover, and the *graben* of Southern Hesse in a single Saxon system of folding, of which the motivating force is tangential thrust. Seidl, in some of his discussions, seems to favor vertical isostatic thrust as the motivating force, but the diagrams in his paper on salt-dome exploration seem to teach the lesson of tangential thrust, and he definitely attributes one set of domes to underthrust. Renner's sections of the Middle Leine salt-dome ridge seem definitely to show tangential thrust (resulting in overthrust) as the motivating force. Stier, in his work on the Benthe salt dome, shows the clear impress on the salt core of folding in the same two directions which control the alignment and strike of the salt domes and salt-dome ridges. Lachman and Arrhenius, however, advocate the theory that the upthrust of the salt is due to isostatic forces resulting from the lesser specific gravity of the salt in comparison to the overlying formations. Few of the German salt-dome geologists seem to follow Lachman and Arrhenius far, but many emphasize the importance of the vertical pressure of the overlying sediments upon the salt. There seem to be no advocates among the German geologists for any of the various American theories of salt domes, the volcanic theory, the theory of deposition from ascending brines, the evaporation of brines by escaping gas. The impression that the writer has gained from the discussions, diagrams, and sections of the German domes is of a relatively mobile substance, the salt yielding under pressure by plastic flow rather than by fracture, or by simple bending in the case of the ordinary sediments.

Significant points in regard to the German salt dome in connection with the American salt-dome problems are: (1) The salt occurs in a series of normal sedimentary beds which can be recognized in a practically constant section throughout the salt domes. (2) The Middle Leine salt-dome ridge and the salt-dome ridges of the Magdeburg-Halberstadt basin are plainly the result of the tectonic deformation of the sedimentary salt series. (3) The salt domes of the North German plain are so intimately connected with the salt domes of the Magdeburg-Halberstadt basin and with the Middle Leine salt dome, and there is such a complete transition between them, there seems to be no reasonable doubt that all the German salt domes have been formed by the same forces, although, in the different areas, the domes may have been cast in slightly different molds. (4) Where the cover above the salt series is only moderately thick and composed of only moderately consolidated beds, the salt dome tends to take the form of an anticline with the flanks of the salt concordant with the flank beds; where the cover is thick and composed of weakly consolidated sediments, the salt core tends to pierce the cover and form a diapir fold. (5) In the North German plain, the flat-lying (mother) salt series of the inter-salt-dome areas have not been found, for the reason that the stratigraphic horizon at which they occur is buried to great depths. (6) The salt domes seem to be due primarily to the fact that massive salt deposits possess a mobility far above that of other sediments, and yield to thrust by plastic flow. (7) The salt domes of the North German plain, such as the Benthe, Wathlingen-Hänigsen, Habighorst-Höfer salt domes, and all the salt domes of the Lower Elbe are very similar to the American salt domes and do not differ from them in any essential way.

CONCLUSION

In the light of knowledge now at hand it is evident that the salt domes of Texas and Louisiana represent essentially the same type of geologic structure as the German and Roumanian salt domes. Due to the difference in the geologic setting of the domes of the respective countries, the American domes differ from the Carpathian–Sub-Carpathian domes and from the German domes in the form which this type of structure has assumed, but where the geologic setting is the same, as, for example, in the North German plain, very closely similar forms have been assumed. In the light of this innate similarity of structural pattern it is evident that the American salt domes probably have been formed by the same general forces acting according to the same general laws that formed the German and Roumanian salt domes.

It is evident that some of the rather characteristic features of the American salt domes are not essential features of salt-dome structure. Although not present on all domes, the limestone-gypsum-anhydrite cap is distinctly characteristic of the American salt domes. Yet the Roumanian domes are without any such cap and the gypsum cap of the German domes seems possibly to be different in origin from the American cap rock. Native sulphur is characteristic of the cap rock of a large number of the American domes, and on some of the domes is present in large quantity, but no sulphur is reported from either the Roumanian or the German salt domes. The accumulation of considerable quantities of petroleum is characteristic of a large number of the American and Roumanian domes, but only minor amounts of petroleum are found around the German domes. On the problems of such features of the American domes little or no light is shed by the knowledge available in regard to the Roumanian and German domes.

A minor feature on which light is shed by knowledge of the German salt domes is the origin of what the writer calls "secondary mounds," "subsidiary crests," and "salt spines." The small mound in the northwest quadrant of the Vinton salt dome is a secondary mound. The more marked crests of the Damon Mound salt-dome mound are subsidiary crests. The crest of the salt core of the New Iberia dome is a salt spine. On the basis of physiographic study of Vinton, Barbers Hill, Big Hill-Jefferson, and Damon Mound, the writer became convinced that secondary mounds are due to secondary upthrust affecting only part of the salt core, and that the subsidiary mounds are either due to secondary upthrust or to differential upthrust with several centers of maximum movement. The belief was strengthened by a study of the structure of the New Iberia dome, where a spine of salt rises 1,200 feet (360 m.) above a much broader salt table. The sections of the Hannoverian type of salt domes (Figs. 10 and 11) seem to show that the older salt has streamed up through the overlying younger salt along several centers or axes of movement. The assumption would seem to be warranted that rate of upward movement should be greater along such axes or centers than along the interaxial lines. Such differential movement, if expressed at the surface, should produce a series of subsidiary mounds such as are present at Damon Mound. It would also seem not unreasonable to expect that later movement of minor amount might take place along one of these axes or centers and not along the others. Such movement would tend to form salt spines, and secondary or subsidiary mounds.

In connection with the more important problems, the following points seem to be evident:

Carpathian-Sub-Carpathian domes:

1. The salt domes are abnormal anticlines characterized by a core of the plastic salt and marl of the Salifere that has been intruded vertically upward into the overlying formations.

2. These anticlines tend to be on structural-trend lines that reflect the effect of the Carpathian tectonics.
3. The structural setting in which the domes occur has exercised a strong control on the form and occurrence of the salt domes.

Transylvanian domes:

1. The domes tend to occur on anticlinal lines.

German domes

1. The salt occurs in relatively normally lying sedimentary formation, in salt domes, and in salt-dome ridges.
2. The salt domes tend to occur on the extensions of the anticlinal axes of the salt-dome ridges, and on other anticlinal axes. The domes very commonly are at the intersection of anticlinal axes.
3. In the salt domes and salt ridges the salt forms the core. In some cases it is in concordant, and in the other cases in diapir, relations to the surrounding sediments.
4. The salt cores have been formed by deformation of the sedimentary salt formation, the salt of which has yielded by plastic flow and has been thrust or intruded into its present position.

From the other papers of the symposium on salt domes it can be seen that the flank beds of the American domes show the effects of very marked upthrust.

In the light of present knowledge it seems futile to predicate the origin of the American salt domes by any other method than by upward intrusion consequent upon, and coincident with, plastic yielding to deformation by a pre-existing salt mass, in all probability an originally flat-lying sedimentary salt bed. Especially does it seem futile since the opposing American theories are based on only very scanty positive evidence, or are based entirely on assumptions. The theory of the precipitation of the salt from ascending brines, whether by cooling or by evaporation by escaping gas, for example, is based on the assumptions: (*a*) of the possibility of an open channel leading upward through thousands of feet of gumbo and shale; (*b*) of the channel being kept open for geologic ages in soft, unconsolidated formations in which the driller has great difficulty in keeping a drill-hole open, even with the hole full of heavy mud; and (*c*) of the existence of ascending streams of brine. No such streams of brine are known to occur around the Gulf Coast salt domes. The presence of small brine springs at the surface would be of no significance in any case, since the German salt domes commonly happen to be characterized by brine springs. The volcanic theory seems to have been proposed without any basis of positive evidence. There are, however, certain local relations in the Transylvania basin, and locally in south Texas, which have been interpreted by reputable geologists as pointing to a possible volcanic origin of salt domes. In the main salt-dome area of Texas and Louisiana, however, the salt domes are not accompanied by evidence of volcanic or even solfateric activity, and the Gulf Coast salt domes seem to be characterized by rather low geothermal gradients to the deeper horizons (about 100 ft. per 1° F.). In the German salt-deposits areas, where there has been volcanic activity there are no salt domes.

That the mother salt-beds of the American salt domes have not been discovered as yet is expectable on the basis of our knowledge of the German salt domes, and can in no way invalidate the theory of the derivation of the American salt domes from such beds. In the area of the German salt domes similar to the American salt domes, the mother salt-beds have not been reached, but there the inference is definitely warranted that they are present at depths which it is not now practicable to reach by boring.

What the motivating force of the intrusion is still remains an open question, even in the added light of the German and Roumanian salt domes. In the case of the Roumanian domes it is easy to call upon orogenic thrust. In Germany a mild orogenic thrust can be called upon, for there were repeated movements of mild folding. The general region in which the American salt domes occur has been one of the great geologic tranquility for a very great distance back into the geologic past. From the salt domes, especially from the Gulf Coast domes, it is far to any region which shows the traces of compressive folding. The static thrust of the overlying cover is not an entirely satisfactory acceptable alternative. It seems inadequate in comparison to the magnitude of the task. The German domes, furthermore, offer very pertinent evidence against the theory of vertical thrust in that there is a very prevailing tendency toward thickening of a bed at the crest of an anticline. Under merely vertically acting forces the crest of an anticline should be a point of thinning. Recrystallization approximately in place may well have occurred, but the evidence of the German domes seems to be against any very considerable transfer of material by solution and recrystallization. Whatever the motivating force, the movement of the salt in the German domes seems to have been by plastic flow, and the force of growing under crystals recrystallization, therefore, seems a dubious motivating force.

In connection with the question of the alignment of the salt domes and the significance of alignment, the lesson of the German and Roumanian domes is that the salt domes are associated with anticlines rather than normal fault lines. To a certain extent the German domes indicate that domes of the American type occur at the intersection of anticlinal ridges. A most significant suggestion which the German domes offer is that the alignment of the salt domes of such an area as the Gulf Coast, with its enormously thick section of unconsolidated sediments, is controlled by the tectonic plan of the underlying basement.

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MAPS OF THE GERMAN GEOLOGICAL SURVEY SHOWING SALT DOMES

Salt Dome	Blatt	Lieferung	Year of Publication
Upper Aller	Gr. Twülpstedt	185	1914
Upper Aller	Weferlingen	185	1914
Upper Aller	Helmstedt	185	1914
Doorn	Süpplingen	185	1914
Fallersleben	Heiligendorf	185	1914
Flackstöckheim	Salzgitter	174	1912
Gr. Rhuden	Lamspringe	182	1915
Habighorst-Höfer	Beedenbostel	187	1915
Hänigsen-Wathlingen	Wathlingen	187	1915
Hänigsen-Wathlingen	Burgdorf i. H.	232	1921
Hildesheimer Wald	Sibbesse	182	1915
Middle Leine Valley	Gronau	127	1906
	Alfeld	127	1906
	Freden	127	1906
Lüneburg	Lüneburg	108	1912
Peine-Nord	Peine	232	1921
Salzgitter	Sazgetter	174	1912
Sperenberg	Sperenberg	243	1922
Stade	Staden-Hagen	106	1904
Stassfurt	Stassfurt	177	1913
Connecting zone between Stassfurt and Aschersleben	Güsten	177	1913
Vienenburg	Vienenburg	174	1912
Wietze-Steinförde	Winsen a.d. Aller	187	1915

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Lieferung XI, Blätter Braunschweig, Magdeburg, Goslar, Dessau, 1922.

INTERIOR SALT DOMES OF TEXAS[1]

SIDNEY POWERS

ABSTRACT

This paper describes the geology of the six interior salt domes in eastern Texas and discusses their relationship with the geology of the region and with the interior salt domes of Louisiana.

INTRODUCTION

LOCATION

Salt domes in the United States are confined to the Gulf Coastal Plain of Louisiana and Texas in an area of very thick sediments and gentle folding. One or two domes are reported in the northeastern corner of Mexico near Brownsville and others are suspected under the waters of the Gulf. No salt domes are known east of the western edge of the Mississippi River delta. The salt domes of the Isthmus of Tehuantepec are in a region of similar thick sedimentation and gentle folding, but domes in some other parts of the world are associated with intense mountain building.

Division of the salt domes of the United States into coastal and interior is based on geological and geographical grounds. A broad belt of country coinciding with the outcrop of formations of Oligocene age lies between the groups on the north and those of the coastal belt. Their location is shown in Figure 1.

Interior salt domes are divided into two groups, one on the axis of the geosyncline of eastern Texas, the other near the axis of the corresponding geosyncline of northern Louisiana. The six interior domes in Texas are described in detail below. There are many other salines in eastern Texas which are not salt domes. Northern Louisiana has thirteen known domes and has many more salines which appear not to be salt domes. The scarcity of exposures and the lack of wells render the classification of many salines difficult. Three salt domes were discovered in northern Louisiana by geologists in 1922. Other domes will undoubtedly be found in the same general area. A question has been raised concerning the origin of the large structural domes on which the Homer and Bellevue fields are located, but these folds embrace many square miles whereas the proved salt domes cover only about three square miles each. The larger folds seem to be the expression of tangential compression accentuated, possibly, by buried hills.

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[1] Published by permission of the Amerada Petroleum Corporation.

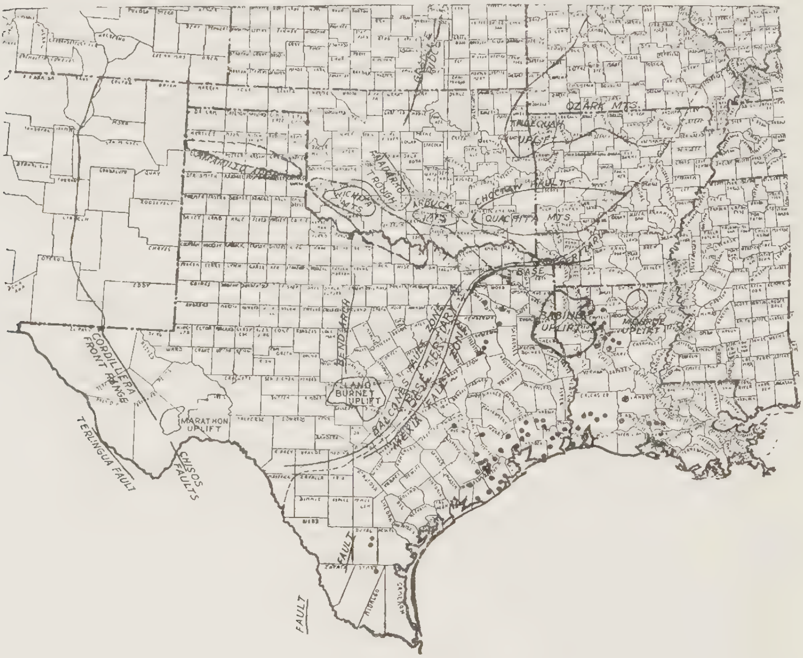

FIG. 1.—Outline map of Texas, Louisiana, Arkansas, and Oklahoma showing relationship of coastal and interior salt domes (dots) to the Sabine and Monroe uplifts (as outlined by Upper Cretaceous structure contours), and to other structural features.

The present Wichita Mountains are extended to include the amarillo arch on the west and the Red River arch–Healdton and Criner Hills buried flanks on the east. The Arbuckle Mountains are extended southeastward by new discoveries and the Sabine uplift as outlined in Lower Cretaceous strata, with northwest-southeast axis is a buried part of the Arbuckle line of folding. The Monroe uplift may be another parallel, buried Paleozoic ridge of pre-Ouachita Mountains generation. The "Granite Ridge" (Nemaha Mountains) and Bend arch may represent a line of Mississippian continental fracture whose counterpart is found in the Balcones and Mexia fault zones.

EXAMINATION

The interior domes of Texas were first described in the first, second, and third annual reports of the Texas Geological Survey under the direction of Mr. E. T. Dumble.[1] The next series of reports by O. B. Hopkins, by E. DeGolyer, and by the writer,[2] form the basis for the present paper which is largely a résumé of the literature. The writer has visited each of these domes several times since the summer of 1916 and desires to emphasize the wealth of information regarding physiography and geology which could be amassed by intensive study of each of them. A number of other geologists have made private reports on one or more of the domes and the reports of Alexander Deussen and L. C. Chapman have been used in the preparation of this paper. The writer is indebted for information to Alexander Deussen, Wallace E. Pratt, Dr. L. W. Stephenson, and Dr. Julia A. Gardner, and, for many courtesies, to M. A. Davey, of Palestine, Texas. Miss L. L. Lane, of the Marland Oil Company of Texas, Miss A. C. Ellisor, of the Humble Oil and Refining Company, Miss H. T. Kniker, formerly of the Texas Company, A. L. Selig and F. X. Bostick of Shreveport, Louisiana, have very kindly identified micro-faunas from several of the domes as well as from the normal outcrop of the same formations.

The Louisiana interior domes were described in detail by Veatch[3] and later by Harris[4] and are being described by W. C. Spooner in a paper of this series in the *Bulletin*.

References are omitted from the text because the present paper is a recapitulation of those already cited. Errors in previous papers have been corrected without explanation. Bulletin 736 of the United

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[1] Detailed references are given in the more recent reports.

[2] O. B. Hopkins, "The Palestine Salt Dome (and Keechi Salt Dome), Anderson Co., Texas," *U. S. Geol. Surv. Bull. 661G*, 1917; E. DeGolyer, "The West Point Salt Dome, Freestone Co., Texas," *Jour Geol.* Vol. 27, 1919, pp. 647-63; Sidney Powers and O. B. Hopkins, "The Brooks, Steen, and Grand Saline Salt Domes, Smith and Van Zandt Counties, Texas," *U. S. Geol. Surv. Bull, 736G*, 1922. Also C. A. Cheney, "Salt Domes of Northeastern Texas," *Oil and Gas Jour.*, January 6, 1922, p. 82, reviewed by K. C. Heald, *Amer. Assoc. Petroleum Geologists Bull.*, Vol. 6, 1922, p. 58.

[3] A. C. Veatch, "Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas," *U. S. Geol. Surv.*, *Professional Paper 46*, 1906.

[4] G. D. Harris, "Oil and Gas in Louisiana," *U. S. Geol. Surv. Bull. 429*, 1910.

States Geological Survey is referred to several times in the text. Maps accompanying the reports of the U. S. Bureau of Soils in Smith, Anderson, and Freestone counties show the drainage around these domes.

EXPLOITATION

During the Civil War many of the interior salt domes were exploited for salt and they were one of the most important sources of this commodity available to the South. Steamboat boilers cut through the center longitudinally served as kettles in Louisiana. Salt manufacture by white settlers began, however, much earlier—in 1805 in Louisiana, in 1835 in Texas—but it practically ceased after the Civil War. Salt is now mined at two domes in Texas by means of wells 450 to 500 feet deep. Casing is landed in the cap rock overlying the salt and water is either allowed to run down from upper sands or is pumped down to the salt and in either case is pumped up into evaporating pans in the plants. Steam evaporation was introduced in Texas about 1886.

Salt was evaporated during the Civil War in Louisiana, at Bistineau, King, Rayburn, Drake, and Cedar salines; in Texas at Grand Saline, Steen, Brooks, and Palestine salines. Salt has been mined for many years at Grand Saline and at Palestine saline.

Limestone has been quarried, principally for the manufacture of lime, at the Winnfield marble quarry and at Pine Prairie salt dome, Louisiana, and at Steen and Brooks salines, Texas. The limestone at Winnfield and Pine Prairie is cap rock and has been extensively quarried for a number of years. Calcareous sandstone was quarried for a short time at Steen saline, but the percentage of lime was too small. The Austin chalk furnished excellent lime at Brooks saline during the Civil War.

Sulphur is practically unknown in the interior domes, although it is exploited in several coastal domes.

Neither oil nor gas has been found in commercial quantities in any interior salt dome with the possible exception of the showing of heavy oil at Keechi. Only two Texas domes, Brooks and Keechi, have been tested and neither of them has been condemned except in very limited areas. A number of wells are required to condemn a salt dome. The outline of the salt core is seldom as regular as indi-

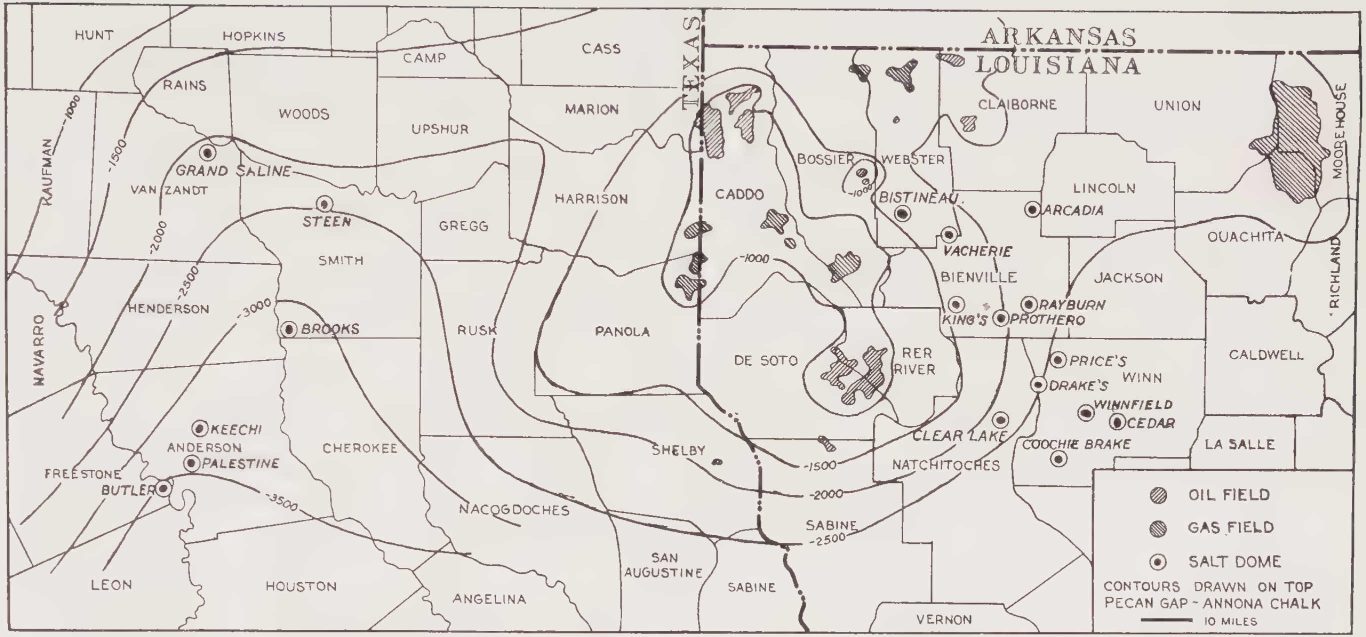

FIG. 2.—Subsurface structure contour map of eastern Texas and northern Louisiana contoured on the top of the Pecan Gap and Annona chalks (assuming them lithologically continuous).

Contours are below sea-level with intervals of 500 feet ignoring faults. The interior salt domes are near the axis of the eastern Texas geosyncline and on the eastern flank of the Sabine uplift. The areal distribution of the Wilcox and Claiborne is shown by broken lines. Contours in Louisiana modified from manuscript map of W. C. Spooner.

cated by surface topography and geology, and wells are drilled unexpectedly into salt. The sides of the dome plunge sharply and may be squeezed or faulted so that wells miss a normal section. The supposition that the oil disappeared at the time of the salt intrusion is not supported by facts; Vacherie and Arcadia salt domes Louisiana, are completely covered by sands which produce oil elsewhere, but salt water only on these domes.

Production may be obtained in any of a number of sandy horizons in the Upper Cretaceous and wells should be carefully drilled, cored at each change of formation, and the cores examined microscopically for fossils to determine the stratigraphic horizon. The oil possibilities of eastern Texas invite exploration.

GEOLOGY

STRATIGRAPHY

The interior salt domes of Texas and Louisiana north of the outcrop of the Oligocene are confined to the outcrops of the Wilcox and Claiborne groups, both of Eocene age, but wells have been drilled through the Upper Cretaceous and into the lower group of the Lower Cretaceous. Formation names change at the Texas-Louisiana line. The formations themselves thicken and thin and change both in lithologic character and in age.

Geologic subdivisions according to age equivalence are given in Table I.[1] The thicknesses of formations change as shown in Plate 1 and estimates are given for the section at each salt dome in the description of the dome. Formations on the eastern side of east Texas are more similar to those in Louisiana than to those in central Texas and are best designated with their Louisiana names.

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[1] These are taken from the following sources: G. D. Harris, "Oil and Gas in Louisiana," *U. S. Geol. Surv. Bull. 429*, 1910; Alexander Deussen, "Geology and Underground Waters of the Southeastern Part of the Texas Coastal Plain," *U. S. Geol. Surv. Water Supply Paper, 335*, 1914; E. T. Dumble, "The Geology of East Texas," *Univ. of Texas Bull. 1869*, 1918; L. W. Stephenson, "A Contribution to the Geology of Northeastern Texas and Southern Oklahoma," *U. S. Geol. Surv. Professional Paper 120H*, 1918; *Prof. Paper 81*, 1914, Pl. 12. Also A. C. Ellisor, *Amer. Assoc. Petroleum Geologist Bull.*, Vol. 9, 1925, and W. C. Spooner, *Monroe Gas Field, Louisiana.* Dept. of Conservation, Shreveport, 1926.

In Louisiana, Coochie Brake, Winnfield, and Cedar Creek salt domes are in the belt of outcrop of the Yegua (Fig. 2), the others in that of the St. Maurice. In Texas, Grand Saline dome is entirely within the Wilcox, the others are near the outcrop of the base of the Mount Selman formation.

TABLE I

	Central Texas	Eastern Texas	Northern Louisiana
Eocene	Claiborne group	Claiborne group	Claiborne group
	Yegua formation	Yegua formation	Yegua (Cockfield) form.
	Cook Mountain formation	Cook Mountain form.	St. Maurice form.
	Mount Selman formation	Mount Selman form.	Sparta sand*
			Cane River*
	Wilcox group	Wilcox group	Wilcox formation
	Carrizo sandstone	Carrizo sandstone	
	Indio formation	Indio formation	
	Midway formation	Midway formation	Midway formation
Upper Cretaceous	Navarro formation	Arkadelphia clay Nacatoch sand Unnamed shale	Arkadelphia clay Nacatoch sand
	Taylor marl	Pecan Gap chalk Wolfe City sand Annona tongue	Marlbrook marl (including Saratoga chalk) Annona chalk Brownstown marl
	Austin chalk	Blossom sand Unnamed clay and sand (including Ector chalk)	Bingen group
	Eagle Ford clay	Eagle Ford formation	
	Woodbine sand	Woodbine sand	Unconformity
Lower Cretaceous		Washita group Fredericksburg group Trinity group	Washita group Fredericksburg (locally absent) Trinity group
Pennsylvanian (?)			
Permian (??)			
Pre-Cambrian			

* New formation names introduced by W. C. Spooner in manuscript.

There are adequate published descriptions of formations in Texas[1] except for the Wilcox, which has been made into a group of two or more formations, and the Austin and Annona chalks, the ages of which are not positively determined.

The Wilcox in east Texas consists of lignitic sandy shales below and sands above. The lower part has been called the Lignitic[2] and the Indio[1] but the former term has suffered so many redefinitions that the latter is accepted. The upper part has been called the Carrizo sandstone in southwestern Texas and the Queen City sand in eastern Texas and has been placed in the Claiborne group until recently. The more widely accepted term Carrizo is used instead of Queen City.[2] The Indio formation has yielded plant remains of Lower Wilcox age,[3] foraminifera and ostracods, both above and below lignite beds[4]—in more localities than have been published—and, in southwestern Texas, a fauna of lower Wilcox age.[5] The Carrizo sandstone in southwestern Texas has yielded plant remains of upper Wilcox age and at Sabinetown[6] and, possibly, at Palestine salt dome a fauna of upper Wilcox age.

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[1] Descriptive sections from well logs are given by F. Julius Fohs, "Structural and Stratigraphic Data of Northeast Texas Petroleum Area," *Econ. Geol.*, Vol. 18, 1923, Pl. 13.

[2] E. T. Dumble, *Univ. of Texas Bull. 1869*, 1918, p. 37.

A division of the Wilcox is difficult to map except in limited areas and is not attempted in the detailed maps of the salt domes. The top of the Wilcox is likewise difficult to determine, and the boundaries in Figure 2 are taken from previous publications.[7]

Confusion of chalks has arisen because at least three are exposed at the outcrop in one county (Fannin): the Pecan Gap chalk member of the Taylor Marl, and the Ector tongue and Annona tongue of the Austin chalk. At least two chalks, the Pecan Gap and Austin, are recorded in well logs as far east as Cherokee County. In east central Texas both may carry a Taylor fauna, though not the same fauna, and in northern Louisiana the Annona chalk carries a Taylor fauna. The upper part of the Annona in Louisiana (the *Ananchytes* zone of White Cliffs, Arkansas) is paleontologically and lithologically the equivalent of the Pecan Gap of Texas and the lower part is equivalent to the lower part of the Pecan Gap or to associated chalk lentils. The paleontological equivalent of the Austin chalk in Louisiana may be the Blossom sand and part of the Brownstown; the chalk itself is believed to lens out in Rusk County. The so-called "Woodbine" oil sands in Louisiana were thought to occur in and above the Eagle Ford and not to be equivalent to the Woodbine sand of Texas,[1] but recent determinations by F. X. Bostick place them under the Buda limestone of Lower Cretaceous age on the Caddo Uplift.[2]

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[1] A. C. Trowbridge, "A Geologic Reconnaissance in the Gulf Coastal Plain of Texas Near the Rio Grande," *U. S. Geol. Surv. Professional Paper 131D*, 1923; Alexander Deussen, "Geology of the Coastal Plain Region of Texas West of the Brazos River," *U. S. Geol. Surv. Professional Paper 126*, 1924.

[2] Wm. Kennedy, "The Eocene Tertiary of Texas East of the Brazos River," *Acad. Nat. Sci. Proc. for 1895, 1896*, p. *135*; *Geol. Surv. of Texas, Third Ann. Rept.*, 1892, p. 50; Alexander Deussen, *U. S. Geol. Surv. Water 1914*, p. 44.

[3] E. T. Dumble, *op. cit.*, p. 40; E. W. Berry, *U. S. Geol. Surv. Professional Papers 91H*, 1916, *131A*, 1923, *132E*, 1925.

[4] A. C. Trowbridge, *op. cit.*, p. 90.

[5] Julia A. Gardner, "Fossiliferous Marine Wilcox in Texas," *Amer. Jour. Sci.*, Vol. 7, 1924, pp. 141–45.

[6] G. D. Harris, *Geol. Surv. of La., Report for 1898*, p. 67.

[7] G. D. Harris, *U. S. Geol. Surv. Bull. 429*, 1910; W. C. Thompson, "The Midway Limestone of Northeast Texas," *Amer. Assoc. Petroleum Geologists Bull.*, Vol. 6, 1922, p. 326; F. Julius Fohs, *op. cit.*, Pl. 12; Alexander Deussen, *U. S. Geol. Surv. Water Supply Paper 335;* E. T. Dumble, *Univ. of Texas Bull., 1869.*

A remarkable thickening of the stratigraphic section in east Texas is found from the middle of the Claiborne group through the beds of Taylor age, the lowest available for study, as shown in the cross-section, Plate I. The greatest thickening appears to be in the Wilcox and in the Taylor. Other formations can seldom be delimited in well logs.

GEOLOGIC HISTORY

Geologic history in the Gulf Coastal Plain is shrouded in the ancient and obscure Llanoria,[3] a fragment of which is visible in the Llano-Burnett horst of central Texas. Wells east of, but close to this horst find pre-Cambrian schist or Cretaceous igneous rocks. Wells at Fort Worth and on the Preston anticline find Pennsylvanian shales beneath the Cretaceous. Wells elsewhere in the Coastal Plain except in Cooke, Grayson, and Denton counties and along the Red River in Lamar and Red River counties, Texas, have not gone through the Lower Cretaceous, but those which have reached older rocks indicate that the Sabine uplift is a portion of the Arbuckle Mountains uplift of Middle Pennsylvanian and Permian age (Fig. 1).[4]

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[1] G. C. Matson and O. B. Hopkins, "The De-Soto-Red River Oil and Gas Field, Louisiana," *U. S. Geol. Surv. Bull. 661*, p. 115; W. M. Winton and Gaylor Scott, "The Geology of Johnson Co., Texas," *Univ. of Texas Bull. 2229*, 1924, p. 31.

[2] Personal communication, September, 1925, from Mr. Bostick.

[3] H. D. Miser, "Llanoria," *Am. Jour. Sci.*, Vol. 2, 1921, pp. 61–89.

[4] The writer postulates a buried extension of the Wichita Mountains with the "Red River arch" on the south flank and the Healdton-Criner hills on the north flank and a buried extension of the Arbuckle Hills to connect with or include the Sabine uplift,

Red potash salt was discovered by the Rycade Oil Corporation on the Markham Texas salt dome in 1924[1] and red algae from this salt have been identified by Professor Josephine E. Tilden of the University of Minnesota as *Phormidium antiquum* n. sp. identical with red algae collected by the writer in the Permian salt mine at Kanopolis, Kansas.[2] This discovery is the first positive evidence of the Permian age of the Gulf Coast salt, but nothing is known regarding associated sediments and possible local Permian basins between the truncated mountain ranges of Llanoria were not connected with the Permian basin of western Texas.

Professor Charles Schuchert writes concerning the algae as follows:

> It is clear what you have discovered, but the fact that the same apparent species of algae occur in the Permian salt of Kansas and in the salt of a salt dome of Texas does not prove at all that both salts are of the same age. Algae are such long-lived plants, and the fossil ones preserve so little of their original structures, that I think one should be cautious about saying that, on the basis of algae, the salt of the salt domes of Texas is to be correlated with the Permian. We need something in the way of fossils that is more dependable than algae, to determine the age of the salt in the Texas salt domes.[3]

Coastal Plain sedimentation as known from outcrops started in Lower Cretaceous time and Dumble[4] has called attention to the fact that the Trinity carries gypsum in Arkansas and in West Texas. Gypsum and anhydrite are also found in thick beds in the Lower Cretaceous in the Pine Island oil field, Louisiana. The Trinity is locally red in southern Oklahoma and it may contain some salt.

Lower Cretaceous sediments consisted of sand and sandy shale at the base overlain by limestone and shale, limestone being very

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marked by the Bailey Development Company well in northern Lamar County with schist at 1,880 feet and the Lady Alice well in northern Red River County, Texas, with schist at 1,673 feet south of a deep Lower Cretaceous trough proved by wells in sec. 2, T. 13 S., R. 31 W., 3,363 feet deep, and in sec. 15, T. 13 S., R. 29 W., 3,780 feet deep, Little River County, Arkansas, both of which stopped in Lower Cretaceous.

[1] E. DeGolyer, "Discovery of Potash Salts and Fossil Algae in Texas Salt Dome," *Am. Assoc. Petroleum Geologists Bull.*, Vol. 9, 1925, pp. 348–49.

[2] Personal communication from Professor Tilden.

[3] Letter, October 5, 1925.

[4] E. T. Dumble, *Amer. Inst. Min. Engrs. Bull. 143*, 1918, p. 1634.

abundant. The Lower Cretaceous has been divided into three groups of formations of which the Trinity at the base has become of great economic importance since the discovery of oil and gas in the Glen Rose formation on the Sabine uplift. This uplift is now proved to have existed as early as middle Lower Cretaceous time because the Trinity sediments are relatively steeply folded in the Pine Island oil field, and are unconformably overlain by gently folded sediments of the Washita group, the Fredericksburg group being absent. The "Woodbine" oil sands and red shales of the Washita group may represent another period of uplift and the absence of the Woodbine formation of Texas indicates a period of erosion after deposition of the Buda limestone.

Upper Cretaceous sediments rest unconformably on the older series and overlap them in Arkansas. The younger series consists of Eagle Ford shales at the base overlain by marls and shales with one or more chalk horizons. Another disconformity separates the Upper Cretaceous from the marine Midway formation of the Eocene which contains limestone in east Texas. A largely non-marine sandy phase, the Wilcox group, follows the long succession of marine strata. The Wilcox is disconformable on the Midway and overlaps it in Arkansas. The lower part of the Wilcox does not cover the Sabine uplift.[1] Eocene sediments in the Eastern Texas geosyncline are thicker than in the corresponding Louisiana geosyncline. Renewed uplift took place at least as early as the beginning of Wilcox time. The Claiborne group of sediments lies disconformably upon the Wilcox group and the complete Claiborne series was probably never deposited on the Sabine uplift. This uplift took the form of an enormous terrace with a north-south axis, but did not assume its present outline until later because younger sediments are more steeply tilted south of it than in the geosynclines on either side.

The interior salt domes of Louisiana and Texas have had similar life histories. The salt was derived from the same horizon in Permian sediments. The domes commenced growing by salt flowage at the same time probably in the Lower Cretaceous, according to Spooner, and may have had later contemporaneous periods of growth. Uplift was not pronounced until late in Wilcox sedimentation and then only in Texas where the Wilcox is steeply tilted whereever exposed on the flanks of the domes. The Claiborne beds show less tilting. Growth of the domes did not permanently cease, however, until after the Claiborne sediments were deposited because they are uplifted in several Louisiana domes. Whether or not uplift continued into the Oligocene as in the semi-interior domes, Brenham, in Texas and Pine Prairie in Louisiana, or even into more recent time, is uncertain, but possible.[1]

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[1] Personal communication from W. C. Spooner. Locally the hiatus is greater than shown by Berry (*U. S. Geol. Surv., Professional Paper 132 E*, 1924).

Dome formation was probably initiated by deep seated faulting corresponding to the shearing visible in the Tahlequah (Ozark) uplift and in the Pennsylvanian sediments in Oklahoma and also exposed in the pre-Cambrian of the Llano-Burnet region. It was genetically connected with the movements which brought about the formation of the Sabine uplift, the corresponding Llano-Burnet horst, and the Balcones and Mexia fault zones and intervening graben and other lines of faulting yet to be discovered. These movements were the breaking down of the Coastal Plain with a shearing stress which created fault zones—or rejuvenated old lines of weakness according to Dr. Udden.[2]

A second period of folding affected the salt domes and the Sabine uplift. It followed the deposition of the Claiborne group and preceded the deposition of the Oligocene. The compression was from north to south, or, more exactly, from north-northwest to south-southeast, forming the cross axes and domes on the Sabine uplift and the other numerous domes and anticlines of northern Lousiana and northeastern Texas and defining both the Sabine and Monroe uplifts in their present form.[3] Faulting, as revealed at Homer, Bull Bayou, Stephens, Irma, Smackover, and elsewhere accompanied this movement.

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[1] Charles Schuchert (Discussion of paper by DeGolyer, *Amer. Assoc. Petroleum Geologists Bull.*, Vol. 9, 1925, p. 872) suggests that the salt domes are due to faulting of Llanoria during Cenozoic times and chiefly previous to the Miocene. The coastal domes were intruded after Jackson time and the earlier Oligocene sediments pinch out against them.

[2] J. A. Udden, *Amer. Inst. Min. Engrs. Trans.*, Vol. 57, 1918, p. 1086.

[3] Sidney Powers, "The Sabine Uplift, Louisiana," *Amer. Assoc. Petroleum Geologists Bull.*, Vol. 4, 1920, pp. 117–36. The mechanics of the faulting is discussed by Heath Robinson, *Econ. Geol.*, Vol. 18, 1923, pp. 722–31.

Volcanic activity started in northern Louisiana and southern Arkansas near the close of the Lower Cretaceous with a great thickness of tuffs and other ejectamenta which have been found in one well in the Monroe gas field[1] and in the outcrop of the Bingen formation in Arkansas and Oklahoma. Active volcanoes were numerous near Murfreesboro, Arkansas, and Uvalde, Lockhart, Thrall, and north of Spofford, Texas, and in the Burro Mountains, Mexico, during Taylor sedimentation. Volcanoes in west Texas showered a large part of Texas with ashes in Jackson (Frio), Eocene time. This volcanic activity does not have a proved connection with the salt domes.

COMPARISON OF INTERIOR DOMES OF TEXAS AND LOUISIANA

TABULATION

Table II summarizes the most important characteristics of the recognized interior domes.

TOPOGRAPHY

Physiographic expression of interior salt domes may take one of several types depending largely upon the proximity of the salt to the surface and to the amount of uplift of the formation normally at the surface. The surface manifestations of interior salt domes are as follows: (1) saline prairies or salt licks; (2) lakes with or without surface outlet, often fed by circular drainage; (3) springs or water wells usually slightly mineralized; (4) circular drainage system around a central hill or around a circular row of hills within which lies a saline prairie or lake; (5) exposures of tilted rocks; (6) exposures of cap rock or of formations older than those normally found in the region; (7) cap rock, salt, or rock of formations normally deeply buried found at shallow depths in wells; (8) soils of unusual nature which may contain calcite crystals or other vein-forming minerals with or without slickensides.

Saline prairies not connected with salt domes are found throughout the Gulf Coastal plain[2] and their origin is connected with the

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[1] The Palmer Trust well in SE. cor. NE. $\frac{1}{4}$, sec. 3, T. 18 N., R. 5 E., found volcanic rock from 2,221 to 3,427 feet underlain by Lower Cretaceous (Washita?) sediments. M. N. Bramlette, *Amer. Assoc. Petroleum Geologists Bull.*, Vol. 8, 1924, pp. 342–46 Also, A. F. Crider, "Volcanic Ash in Northern Louisiana," *ibid.*, p. 524.

[2] These are mapped by G. D. Harris, "Oil and Gas in Louisiana," *U. S. Geol. Surv. Bull. 429*, 1910, Pl. 12; they are described by E. T. Dumble, "The Geology of East Texas," *Univ. of Texas, Bull. 1869*, 1920, p. 309.

TABLE II

SALT DOME	SALT CORE					CAP ROCK		SALINE, "LICKS" OR LAKE		WELLS		GEOLOGY		AMOUNT UPLIFT STRATA	DIAMETER AREA UPLIFTED
	Found	Shallowest Known Depth Feet	Top Eroded	Diameter Miles	Mined During Civil War	Found	Depth Feet	Central	Circular around Central Hill	Deepest on Top Dome	Deepest on Side Dome	Normal Surface Formation	Oldest Formation Cropping Out	Feet	Miles
Texas															
Grand Saline	X	235	Yes	1¼	Yes	X	188	X	......	520	3,842	Wilcox	Wilcox	500	2½
Steen	X	300?	Yes	1	Yes	X	75	X	......	600?	2,630	Mt. Selman	Wilcox	500	3
Brooks	X	220	Yes	1½	Yes	X	195	X	......	429	3,193	Mt. Selman	Austin	4,300	3
Keechi	X	2,162	?	1	No	No	......	......	......	3,170	3,048	Mt. Selman	Taylor	3,500	3½
Palestine	X	122	Yes	¾	Yes	X	120?	X	......	700	......	Mt. Selman	Buda	5,500	4¼
Butler	X	312	?	1¼	No	?	......	X	X	1,200	1,220	Wilcox	Navarro	2,500	3½
Louisiana															
Bistineau	X	1,862	Yes	1½	Yes	X	1,420	X	......	2,305	3,245	St. Maurice	Marlbrook	1,500	4
Vacherie	X	777	No	1×1½	No	X	658	X	......	897	2,558	St. Maurice	Arkadelphia	1,500	3×4
Arcadia	X	1,400	No	1½	No	X	1,375	X	......	4,012	3,450	St. Maurice	Arkadelphia	2,350	4
Rayburn	X	115	Yes	¾	Yes	X	At surface	X	......	277	3,003	St. Maurice	Blossom	2,200?	3
King's	X	175	Yes	1	Yes	X	160	X	......	136	2,225	St. Maurice	Marlbrook	2,000	3
Price's	X	1,300?	?	¾	Yes	X	1,100?	......	X	None	?	St. Maurice	Wilcox	1,500	2
Prothero	......	......	?	1×1¼	No	No	......	X	......	None	None	St. Maurice	Blossom	3,000	2½
Drake's	X	900	Yes	1	Yes	X	290	X	......	2,312	1,510	St. Maurice	Wilcox	1,500	2½
Winnfield	X	999	No	1½	No	X	At surface	X	......	1,110	4,021	Cockfield	Wilcox	2,000	2½
Cedar Creek	......	......	?	1	Yes	X	801	X	......	700	3,150	Cockfield	St. Maurice	1,500	3
Coochie Brake	......	......	......	1	No	No	......	X	......	None	3,100	Cockfield	St. Maurice?	1,500	2½
Clear Lake	X	234?	?	1	No	?	......	X	......	......	3,463	Cockfield	St. Maurice	1,500?	2½
Gibsland	......	1,238	......	......	No	X	1,142	......	......	1,520	......	St. Maurice	....	1,000	2

The location of the Louisiana domes is as follows: Bistineau, secs. 35, 36, T. 18 N., R. 10 W.; Vacherie, sec. 16, T. 17 N., R. 8 W.; Arcadia, sec. 29, T. 18 N., R. 5 W.; Rayburn, sec. 31, T. 15 N., R. 5 W.; King's, secs. 34, 35, T. 15 N., R. 8 W.; Price's, sec. 30, T. 13 N. R. 4 W., and sec. 25, T. 13 N. R. 5 W.; Prothero, secs. 7, 8, 17, 18; T. 14 N., R. 6 W.; Drake, secs. 20, 21, T. 12 N., R. 5 W.; Winnfield sec. 19, T. 11 N., R. 3 W.; Cedar Creek, secs. 30, 31, T. 11 N., R. 2 W.; Coochie Brake, sec. 6, T. 9 N. R. 4 W.; Clear Lake, secs. 28, 29, 32, 33, T. 11 N., R. 6 W.; Gibsland, sec. 15, T. 18 N., R. 7 W. (Discovered December 1925).

presence near the surface of rocks containing small quantities of salt or with normally shallow connate salt water brought to the surface along joints and fault planes. Sufficient salt is found in this water to permit salt manufacture by evaporation. Excellent exposures of rock with normal dip are found near some of these salines.

Springs and small mounds[1] are characteristic of salt domes. If the salt is near the surface, salt water issues in salines and "licks" and furnishes the salt evaporated at a number of domes during the Civil War. Sulphur, alum, and other mineralized springs are common and deserve more attention than has been devoted to them.

COMPOSITION

All interior domes are cylindrical plugs over a mile in height with a diameter within 3,000 feet of the surface of ½ mile to 1½ miles. At Grand Saline the top of the core of salt was found in one well at 306 feet and in a well ¼ mile away the salt was not reached at 3,842 feet. The salt core is so nearly cylindrical that wells which enter salt seldom find either sedimentary rock or cap rock beneath. In places wells find alternating beds of salt and shale or cap rock, or else stringers of salt.

The tops of most interior salt domes have been eroded and the surface of the salt is reached at from 200 to 300 feet. The surface of the salt where thus eroded is horizontal and the overlying sediments are probably in part secondary wash deposits.

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[1] The origin of the small mounds is a mooted point because different mounds are formed from different causes. The following is an incomplete list of references discussing their origin:

A. C. Veatch, *U. S. Geol. Surv. Professional Paper 46*, 1906, p. 55.

M. R. Campbell, "Natural Mounds," *Jour. Geol.*, Vol. 14, 1906, pp. 708–17 (Bibliography).

J. A. Udden, "The Origin of Small Sand Mounds in the Gulf Coast Country," *Science, U. S.*, Vol. 23, 1906, p. 849.

W. H. Hobbs, "Some Topographic Features Formed at the Time of Earthquakes and the Origin of Mounds in the Gulf Coastal Plain," *Amer. Jour. Sci.* (4), Vol. 23, 1907, p. 245.

C. H. Gordon, *U. S. Geol. Surv. Water Supply Paper 276*, 1911, p. 32.

G. C. Matson, *U. S. Geol. Surv. Bull. 519*, 1916, p. 12.

William Kennedy, *Southwestern (Amer.) Assoc. Petroleum Geologists Bull.*, Vol. 1, 1917, p. 41.

E. G. Woodruff, *ibid.*, p. 81.

G. S. Rogers, *Amer. Inst. Min. Engrs. Bull. 136*, 1918, p. 285.

R. T. Hill, *Dallas Morning News*, October 2, 1919.

Sidney Powers, *Amer. Jour. Sci.* (4), Vol. 49, 1920, p. 132.

T. L. Bailey, *Univ. of Texas Bull. 2333*, 1924, pp. 22–30 (cites example of mound 20 feet in diameter which has risen under a house).

The salt in salt domes is very pure sodium chloride (96–99 per cent) and is similar to that in bedded deposits.[1] The colorless salt is streaked with black bands as in bedded deposits of Kansas, but these are contorted and squeezed by the intrusion of the salt plug so that a photograph of the salt resembles one of schist.[2] The streaks, according to Harris,[3] "are not caused by any dark substance in the salt, but by the absorption of the rays of light by minute particles of seemingly clear anhydrite. This is proved first by dissolving some of the streak salt in fresh water and noting the 'sand,' as the miners say, that settles at the bottom." He gives the following analyses of salt from Avery's Island to substantiate his conclusions:[4]

	Colorless Salt	Black Salt
Na Cl	99.10	96.53
H_2O	.10	.20
Water insoluble Ca SO_4	.23	2.16
Water soluble Ca SO_4	.33	1.05
	99.76	99.94

Veatch states that "the black salt on Petite Anse (Avery's Island) shows about seven per cent of insoluble matter, part of which is gypsum and the Belle Isle black salt shows about the same amount of insoluble matter, part of which, although a much smaller amount, is gypsum."[5] Black streaks in bedded deposits may also be caused by interbedded shales or clay or organic matter.[6] The only other known impurities in the salt of salt domes is a very small amount of sandstone, colored red by hematite in the Avery's Island Mine.[1] Red salt containing sylvite has been found on the flank of only one salt dome—Markham.

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[1] Chemical analyses may be found in the reports by Harris and by Veatch, cited below, and in *U. S. Geol. Surv. Bulls. 669, 695, 736G;* and in A. W. Grabau, *Geology of the Non-Metallic Mineral Deposits Other Than Silicates*, Vol. 1, *Principles of Salt Deposition,* New York, 1922.

[2] G. S. Rogers, "Intrusive Origin of the Gulf Coast Salt Domes," *Econ. Geol.*, Vol. 13, 1918, p. 468.

[3] G. D. Harris, "Louisiana," *Geol. Surv. Bull. 7*, 1908, p. 7.

[4] *Ibid.*, p. 16.

[5] A. C. Veatch, "The Five Islands," *Louisiana Geol. Surv. Report for 1899*, p. 226.

[6] W. C. Phalen, Personal Communication; also, *Science, U. S.*, Vol. 55, 1923, pp. 479–80.

Cap rocks are very thin shells in the case of most eroded cores. There is cap rock in the center of the dome and the cap on the side increases in thickness as the edge of the dome is reached. The thickness varies from a few to 50 feet. At Winnfield marble quarry, Louisiana, the cap rock is exposed at the surface and is 1,000 feet thick. Cap rock may be found interfingered with the sedimentary rocks as in the Tampico Oil Company's well at Winnfield and more rarely with the salt. The cap rock is in general a thimble confined to the top of the dome and is apparently formed and replaced after the core stops growing. Cap rock may be formed at the end of each period of renewed growth of the dome and apparently this has been the case at Winnfield.

The composition of cap rock is usually anhydrite, gypsum, limestone, or sulphur as described by Goldman.[2] The cap rock of the interior domes of Texas, where known, is limestone.

GRAND SALINE SALT DOME

LOCATION, HISTORY, AND SALT PRODUCTION

Grand Saline, formerly called Jordan's saline, was Cherokee Indian land and is near the northern end of the Spanish land grants. It is located in northeastern Van Zandt County on the Samuel Bell survey. The town of Grand Saline is situated on the northern rim of the dome and the Texas and Pacific Railroad crosses the north side of it. Sabine River is 4 miles northeast of the dome.

Salt was evaporated by the Indians and later by the white settlers starting in 1845. Fred Ham installed the first kettles in 1853 and sold the land to S. Q. Richardson in 1859 who put in a more elaborate plant, a pump operated by a mule and a pipe line of hollowed wooden logs.[1] It was visited by the Army of the Republic of Texas under Gen. K. H. Douglas on July 18, 1839.

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[1] G. S. Rogers, *ibid.*, p. 471.

[2] M. I. Goldman, "Petrography of Salt Dome Cap Rock," *Am. Assoc. Petroleum Geologists Bull.*, Vol. 9, 1925, pp. 42–78. *See* also, E. DeGolyer, "Origin of the Cap Rock of the Gulf Coast Salt Domes," *Econ. Geol.*, Vol. 13, 1918, pp. 616–20; C. W. Washburne, "Oil Field Brines," *Amer. Inst. Min. Engrs. Bull. 164*, 1920, pp. 3–13; E. DeGolyer," "Origin of North American Salt Domes," *Am. Assoc. Petroleum Geologists Bull.*, Vol. 9, 1925, pp. 831–74.

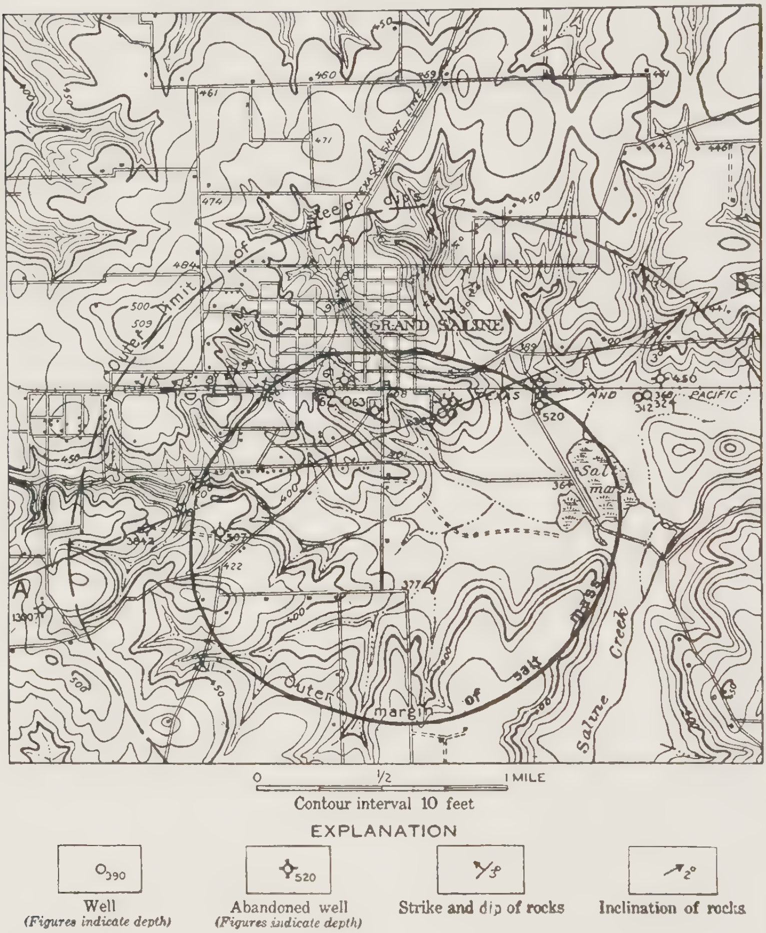

FIG. 3.—Topographic map of Grand Saline salt dome reproduced from *U. S. Geol. Survey Bulletin 736.* The figures at the side of wells refer to their depth. The wells nearest to the railroad station both east and west are salt wells. This dome is an excellent illustration of the physiographic type of dome with a central saline surrounded by hills.

During the Civil War evaporation of salt took place on an extensive scale, 100 tons a day being recovered. The present plant recovers 160 tons a day and the plant at Palestine salt dome 120 tons. The maximum production at Steen Saline during the war was probably 120 tons a day and the larger figure (1,200 tons) given by Burleson[1] in 1874 may have been a typographical error.

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[1] Wentworth Manning, *Some History of Van Zandt County*, Wills Point, Texas, 1919, p. 146.

Richardson erected a plant at the northeastern edge of the salt core near the railroad and converted it into steam evaporation about 1888. The first salt well at Grand Saline was drilled for him by Marsden at about this time. The plant was enlarged about 1900 to a capacity of 750 barrels weighing 280 lbs. each and was operated from 1905 until 1919 by T. S. McGrain as the Grand Saline Salt Company. After two fires the property was sold to the Morton Salt Company and operations ceased.

Major Parsons erected the first plant for steam operation at Grand Saline on the southwest side of the town about 1886. The Lone Star Salt Company, Henry Blount, Southern Salt Company, and Fiedler Salt Company properties all located near together, were absorbed by B. W. Carrington and Company between 1902 and 1906 and later transferred to the Morton Salt Company. The capacity of the Morton plant has grown from 500 to 2,000 barrels a day.

Data concerning salt production has been furnished by Mr. McGrain of Grand Saline and by Mr. B. W. Carrington of Dallas. The total quantity of salt produced from the dome is estimated at 1 million tons or 28 million cubic feet or sufficient salt to lower the surface of the ground 4 feet over an area of $\frac{1}{2}$ square mile. Actual removal of salt has been confined to the northern end of the salt core and the cap rock over the salt minimizes the amount of subsidence at the surface.

More salt has been removed from Grand Saline than from Palestine dome. Comparative production figures for the two domes from the beginning of commercial mining through 1923 where salt is secured by wells as contrasted with the two where salt is actually mined are as follows: Grand Saline, 1,000,000 tons, Palestine 500,000 tons,[2] Avery's Island, Louisiana, 2,578,399 tons, Weeks Island, Louisiana, 1,500,000 tons.

TOPOGRAPHY

Grand Saline is an excellent example of the type of salt dome with a central depression over the salt surrounded by a single ring of hills. If there is concentric drainage it is beyond the limits of the area mapped in Figure 3. The depression consists of a barren prairie with pools of water and a salt marsh drained by Saline Creek, which flows eastward to Sabine River. The creek formerly flowed through a channel north of its present course. Another example of a "wind gap" similar to this abandoned channel is to be observed at Palestine salt dome. Fresh and brackish water springs surround Grand Saline as well as all other salt dome salines in eastern Texas.

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[1] *Texas Geol. and Agr. Survey First Ann. Rept.*, Houston, 1874, p. 223.

[2] Mineral Statistics of the *U. S. Geol. Surv.*, give the total production for Texas to the close of 1923 as above 12,000,000 barrels or 1,750,000 tons.

Solution and removal of salt has not appreciably lowered the surface of the saline although very slow subsidence undoubtedly proceeds continuously. Several salt wells have caved, producing small craters.

The subdued topography is characteristic of the lower part of the Wilcox group. The hills west and north of the saline show outcrops in fresh cuts but the hills on the south and southeast sides are covered with sand which prevents the formation of fresh exposures.

GEOLOGY

Surface geology.—Grand Saline is nearer the outcrop of the Cretaceous formations than any other salt dome in Texas. Around it only the Lower Wilcox (Indio) is exposed. The salt core is overlain by Wilcox and by material which has washed in as the salt has been dissolved. It is 12 miles from Grand Saline to the base of the Wilcox near Wills Point and this group is 500 feet thick in the Lindsey well on the west flank of the uplift. The Wilcox consists typically of sandy shales and sandstones with thin ironstone concretionary beds and lignite beds. Plant impressions were noticed in the shales on the west side of the dome near the reservoir for the salt works.

Underground geology.—A number of shallow salt wells and three tests for oil have been drilled on the top and sides of the salt core. The logs of the wells are given in Bulletin 736 of the United States Geological Survey. The first test for oil, drilled by A. Wilderspin in 1902 to a depth of 875 feet, was located southwest of the dome and is shown near the edge of the map, Figure 4. The Hallville Oil and Gas Company Lindsey No. 1, on the west side of the dome is within the area underlain by the salt core and reached salt at 306 feet. Their Lindsey No. 2 was located $\frac{1}{4}$ mile west and did not reach the salt to a depth of 3,842 feet. The correlation of formations in this well has been the subject of great discussion because accurate correlations from rotary well cuttings without cores cannot be made. The base of the Wilcox is 645 (?) feet, the Pecan Gap chalk member of the Taylor marl was found from 2,664 to 2,740 feet and the Wolfe City sand member of the same formation from 2,740 to 2,960 feet. Dr.

L. W. Stephenson, of the United States Geological Survey, from a megascopic study, and Miss A. C. Ellisor from a microscopic study of cuttings agree that this well, with a total depth of 3,842 feet never reached the Austin chalk or a fauna of Austin age, but Miss Kniker, has found an Austin microfauna. The log of the Jewell and North Texas Oil Company's Davis No. 1, 4½ miles southeast of Grand Saline, on the J. J. Moore Survey, drilled to 4,093 feet shows limey material from 3,852 to 3,998 feet but this has not been identified.

The cross-section of the dome, Figure 4, has been drawn to scale after a study of logs of wells in Van Zandt County. A normal columnar section of the Eocene and Upper Cretaceous is believed to be as follows:

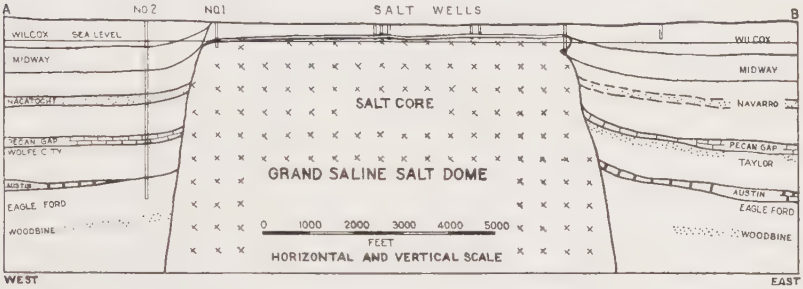

FIG. 4.—Cross-section of Grand Saline salt dome from west to northeast along the line *A–B* of Fig. 3 showing the location of the salt wells of Lindsey Nos. 1 and 2, and the small amount of uplift of strata adjoining the core of salt which is about 1½ miles in diameter. Erosion has truncated the top of the salt core, but has not revealed what has become of the sedimentary rocks from the space now occupied by the salt.

	Feet
Wilcox group	650
Midway and Navarro formations	1,950
Taylor, including Pecan Gap chalk	800
Austin, Eagle Ford and Woodbine	1,000
	4,400

The salt wells are difficult to locate and describe because of occasional changes in the numbering scheme, but they are shown on the map of the dome. One group of four wells drilled by the Grand Saline Salt Company, but no longer used, is located ¼ mile east of the railroad station and south of the track. The next well farther east (east of the town) is the Richardson well drilled by Marsden. The other wells shown on the eastern edge of the map did not reach salt. The original Lone Star Salt Company well is located near one of the buildings of the Morton plant a short distance west of the railroad station and north of the track.[1] The other Morton wells are located south of the track and west of the railroad station and as numbered by the superintendent, Mr. R. A. Egbert, may be described with reference to an imaginary square as follows: No. 1, NE. corner; No. 2 SE. corner; No. 3 SW. corner; No. 4 NW. corner; No. 5 center; No. 6, a short distance east of No. 4. Wells No. 2, 3, 5, and 6 are in use in February, 1924. The logs of the wells drilled in 1918 (Nos. 3 and 4) and in 1923 (Nos. 5 and 6) are given below.

TABLE III

No. 3		No. 4		No. 5		No. 6	
Feet		Feet		Feet		Feet	
0–5	Clay	0–8	Clay	0–2	Sand	0–3	Sand
30	Packed sand	20	Packed sand	12	Clay	15	Clay
80	Quick sand	90	Quick sand	100	Sand	100	Sand
125	Blue mud	210	Blue mud	120	Shale	125	Shale
148	Soapstone	212	Pyrite	145	Soapstone	143	Sandy shale
187	Chalk	238	Lime	155	Gumbo	156	Gumbo
195	Soapstone	400	Salt	164	Soft lime	170	Sandy shale
207	Hard sand			169	Lime and pyrite	172	Pyrite
223	Blue sand			185	Chalk	180	Chalk
225	Pyrite			196	Gravel	203	Black lime
235	Hard blue sand			197½	Cavity	210	Gravel
240	White lime			204	Quicksand	226½	Hard lime
402	Salt			210	Black lime	228	Cavity
				225	Chalk	245	Shale
				226	Cavity	403	Salt
				240	Shale		
				404	Salt		

The depth of the top of the salt in feet in various wells is as follows: Morton No. 1, 235; No. 2, 235; No. 3, 240; No. 4, 238; No. 5, 240; No. 6, 245; Grand Saline Salt Co. No. 1, 245; No. 2, 235; Richardson-Marsden well, 212. Information regarding the two other Grand Saline Salt Company wells is lacking. Lindsey No. 1 found salt at 306 feet. It appears that the salt has been dissolved over the core to a uniform depth and that solution of the salt and subsidence of the roof progressed slowly with the normal erosion at the surface and gradual lowering of the ground water table.

One more well, not numbered, was drilled to 236 feet in 1918 without finding salt and was abandoned.

Limestone and gypsum cap rock overlies the salt and in it casing of the salt wells is set. The new wells report cavities on top of the salt which may be due to solution since the first wells are drilled, but the wells do not seem to have underground connection. The shale below the cavities in two wells may have been washed in from abandoned wells. The thickness of the cap rock varies from 16 to 45 feet. Oil is reported in two wells probably in the cap rock. Water sand is found below the cap rock in some wells and this water furnishes a permanent supply to be pumped from the bottom of the wells drilled 100 to 200 feet into the salt. In other wells and at the Palestine dome water must be pumped into the wells. A thick cap rock is necessary for successful salt recovery by wells because otherwise, as at Lindsey No. 1, the shale caves too badly.

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[1] The log is given by William Kennedy, *Geol. Surv. of Texas Third Ann. Report*, 1892, p. 76, is 359 feet deep. It is reproduced on p. 220, *U. S. Geol. Surv. Bull. 736*.

Structure.—Dip arrows and degree readings in Figure 3 show the quaquaversal folding with a rapid gradation from 20° dips on the inner edge of the bed rock and the outer edge of the wash deposits over the salt core to 1° dips ½ mile away. It is important to note that the salt was formerly in contact with the present inner edge of bed rock and that the original top of the salt core was probably higher than the present surface of the saline prairie (Fig. 3). A plunge of over 3,800 feet in ¼ mile between Lindsey Nos. 1 and 2 in the outer edge of the salt core shows that the core must be a cylindrical plug rising from unknown depths. The original top of the salt plug must have been rounded like that of Jefferson Island, Louisiana.

Interior salt domes are very much smaller and sharper folds than ordinary structural domes in sedimentary formations. The diameter of the Grand Saline salt core is at least 1 mile and probably 1½ miles, and that of the surrounding uplift ½ mile. The Lindsey No. 2 log proves the insignificance of the uplift within ¼ mile of the salt core. The total area affected at the present land surface is 2½ miles in diameter and the amount of uplift of the exposed Wilcox beds less than 500 feet.

STEEN SALT DOME

LOCATION AND HISTORY

The Steen salt dome is in northern Smith County (Fig. 5), 5½ miles east of Lindale, 14 miles north of Tyler, and 2½ miles south of Sabine River. With reference to the Spanish grants it is in the northeast corner of the M. de los Angeles Carmona league. This dome is 24 miles southeast of Grand Saline and 27 miles northeast of Brooks salt dome. It is the northernmost of the five which are roughly aligned. It is 26 miles southeast of Grand Saline and the same distance north of Brooks Saline.

A man named Stein or Steen appears to have acquired the saline about 1866 after the Cherokee Indians were moved to Indian Territory and his name, spelled Steen because of the way in which it was pronounced, has become attached to it. The patentee of a nearby Survey was John Steen and the early reports used this spelling. Little is known of the exploitation of the saline except that 3,000 people were engaged in making salt on it during the Civil War, and that the output is reported to have been 12,000 (?) sacks (1,200) tons[1] daily with 20 furnaces making a bushel of salt from every 190 gallons of water whereas at Brooks Saline only 100 sacks were made with 7 furnaces making a bushel from 300 gallons of water. In Louisiana during the war 100 bushels of salt a day were made at Drake's Saline, 1,000 bushels at Rayburn's Saline, and 350 bushels at Price's Saline.

Wm. C. Scott owned the saline for many years and quarried the calcareous limestone on its west side in 1868–70 burning lime in kilns at the quarry and using it in mortar for houses in Tyler. Silver was sought in the same rock, probably in galena, but the silver was proved by J. H. Herndon to be a myth. No galena has been observed in this rock by the writer.

Two wells were drilled for salt on the Scott estate about 1902 by Lestergett and their depths are reported to have been between 400 and 600 feet. Little is known regarding them and the belief that they reached salt at a depth of about 300 feet and below a hard cap rock cannot be verified. The Lindale Oil Company drilled a well on the Winters farm in 1920 as described below. W. F. Weeks *et al.* drilled a well on the Pierce farm in 1924, and found limestone cap rock from 75 to 207 feet, the total depth in August, 1925. It seems desirable to test these domes by a radial row of wells starting near the salt rather than to scatter locations around the dome and thereby merely outline the salt body for the benefit of the next prospector.

TOPOGRAPHY

Steen dome consists of a central saline marsh surrounded by a ring of low hills which are in turn surrounded by high hills. Trees cover the hills west of the saline and hide the topography. Dense underbrush and trees have encroached on the saline and very little bare ground is left. The swamp is about 6,000 feet long and 2,000 feet wide at the widest point. The saline during the Civil War covered 10 acres. The elevation of the lake is about 350 feet.

Saline Creek, flowing from south to north and emptying into the Sabine River, forms the swamp. Numerous springs empty into

[1] This is evidently a typographical error for 1,200 sacks.

the swamp, but they are not as noticeable as around other domes because the swamp occupies almost the entire depression. Undoubtedly the springs represent artesian water from sands of Wilcox age brought up along the outcrop and along faults and joints at the edge

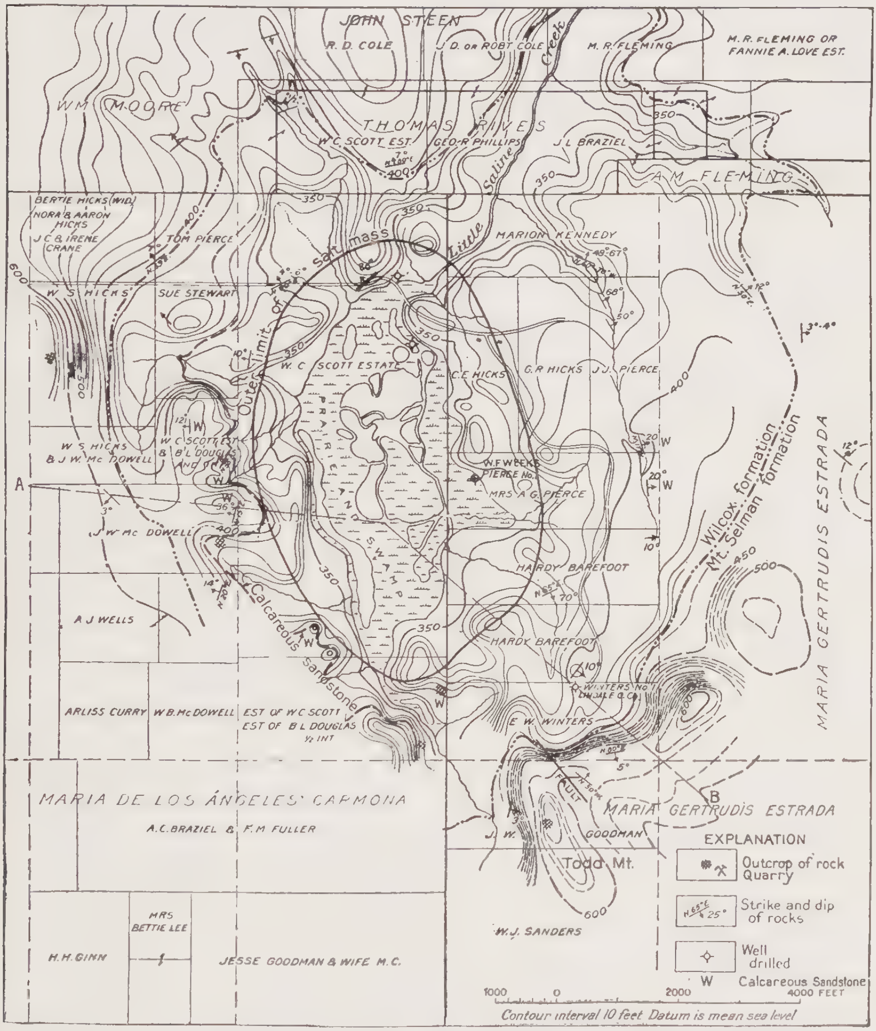

FIG. 5.—Topographic map of Steen salt dome reproduced with minor additions from *Bulletin 736*. This is another example of a central saline surrounded by hills. Circular drainage is beginning to develop outside the inner rim of hills.

edly the springs represent artesian water from sands of Wilcox age brought up along the outcrop and along faults and joints at the edge of the salt core. A sulphur spring occurs in the northeast quadrant of the dome.

The topography is shown in Figure 5. The inner rim of hills rises 60 feet above the saline, the outer rim 150 to 250 feet. Radical drainage into the saline has formed the inner rim of hills from topographic benches of an earlier erosion cycle. Circular drainage is developing east of the saline and two small valleys are being cut behind the lower hills on the west side.

GEOLOGY

Surface geology.—Steen and Brooks salines lie in the area of the dissected Mount Selman formation which produces a pronounced wold and striking hills capped by very hard and resistant red ferruginous sandstone and iron ore. The outer rim of hills surrounding Steen Saline is composed of these sandstones dipping gently away from the dome. The most interesting observed outcrop of the Mount Selman formation is on the ridge south of the Winters well where a fault forms a "stone fence."

Soft red sandstone classified as Carrizo underlies the Mount Selman in Todd Mountain. Mount Selman iron ores, similar to those on Todd Mountain, shown at the southeast corner of Figure 5, were formerly mined at Rusk, in Cherokee County.

Lower Wilcox (Indio formation) sandy shales and sandstones, usually identified by the presence of lignite or of shales of lavender color, bearing plant impressions, underlie the Carrizo sandstone. The low hills and terraces surrounding the saline are underlain by beds of Wilcox age and exposures may be found in gullies. There is a marked discordance of dip between these sandy shales and the ironstones of the Mount Selman which may be observed on the west and southeast sides of the dome.

Calcareous sandstones and calcareous concretions crop out on five hills west of the center of the saline where they have been quarried. Another exposure is in a small creek which is developing a circular drainage pattern east of the center of the saline. Similar rocks are exposed at the south end of the lake. In Bulletin 736 of the United States Geological Survey the exposures on the west side were described as possibly of Midway age, but the later discovery of obscure plant fragments at the quarry indicates Wilcox age. The sandstone is lithologically the same as that in West Point Mountain at Butler dome containing Wilcox plants. At the quarry, which was worked in 1868, a massive bed of gray calcareous sandstone 12 to 15 feet thick forms a miniature hogback with a strike N. 25° E. and dip 40° W. A second ridge of similar rock is found 500 feet west of the quarry and another outcrop occurs on the hill north of the quarry. The other hills are covered with ironstone concretions and remnants of the Mount Selman beds. The lime cementation is probably of very local occurrence and represents a secondary concentration corresponding to the iron in the ferruginous sandstone.

On the east side of the dome an exposure described in *Bulletin 736* on the Mrs. Pierce farm is now concealed but another exposure of calcareous gray sandstone was found southeast of the farmhouse. The dip is N. 70° E.< 20°. This bed is one foot thick, is highly jointed, and is so locally impregnated with lime that it does not crop out in the ploughed field up the dip. The presence of lignite in the water well at the farmhouse in lower beds as well as in water wells at houses near the main highway on the C. E. Hicks farm indicates that the calcareous rock is of Wilcox age.

No exposures of older rocks have been found- but local inhabitants report that many years ago fossiliferous shale was exposed in the first large branch north of the "limestone" quarry. The available stratigraphic section does not tend to verify this report.

The thickness of the Wilcox section below the "limestone" on the east side of the saline is over 100 feet and possibly 200 feet. The interval from this bed to the lowest ferruginous sandstone, near the Winters well is unknown. Between this later outcrop, which may be the base of the Carrizo sand, and the top of the hills 300 feet of Carrizo sandstone (?) is exposed.

Underground geology.—The only available information regarding the subsurface geology is from an analysis of the Winters log. This well starts in the Wilcox and must have passed through several hundred feet of this formation. The sand from 412 to 488 feet may be the base of the Wilcox. Gumbo, shale, and rock with only one thin sand from 488 to 2,495 feet must represent the Midway and the upper part of the Upper Cretaceous. Alternating sand and shale from 2,495 to 2,525 feet and alternating limestone and gumbo from

2,525 to 2,551 feet may represent the Pecan Gap chalk member of the Taylor marl. Shale and sand from 2,551 to the bottom of the hole at 2,630 feet may represent the Wolfe City member of the Taylor marl or the Pecan Gap chalk (Fig. 6).

The normal section may be as follows:

	Feet
Wilcox group	1,100
Midway and Navarro formations	1,900
Taylor including Pecan Gap chalk	1,000
	4,000

Structure.—Quaquaversal folding with dips of 30° to 70° in the Wilcox surround the saline. Intrusion of the salt core has pressed back the surrounding beds, but the effect of the intrusion diminishes rapidly away from the dome. Dips of 2° to 10° in the Mount Selman formation capping the outer rim of hills extend so near the steeply dipping Wilcox beds on the west and southeast sides of the dome that the relationship may be explained at a local unconformity. The Carrizo sandstone may be locally unconformable with the Indio formation of the ferruginous sandy beds on the west side of the dome near the "limestone" quarry. The amount of uplift of the strata nearest the salt core is about 500 feet.

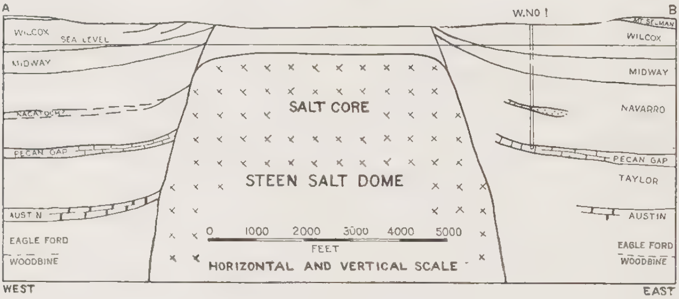

FIG. 6.—Cross-section of Steen salt dome from west to southeast along the line *A–B* of Fig. 5. The salt core is probably cylindrical in form because the area of uplift is small and the Winters well (W. No. 1) showed only slight uplift.

A fault, marked by a "stone fence" of ferruginous red sandstone 5 feet in thickness, is found on the north flank of Todd Mountain and on the southeast side of the dome. The strike of the fault is N. 40° W., and the downthrow is 60 feet or more on the northeast side

The upturned sandstone ridge is on the downthrown side. Slickensided surfaces of the sandstone indicate that the movement was vertical.

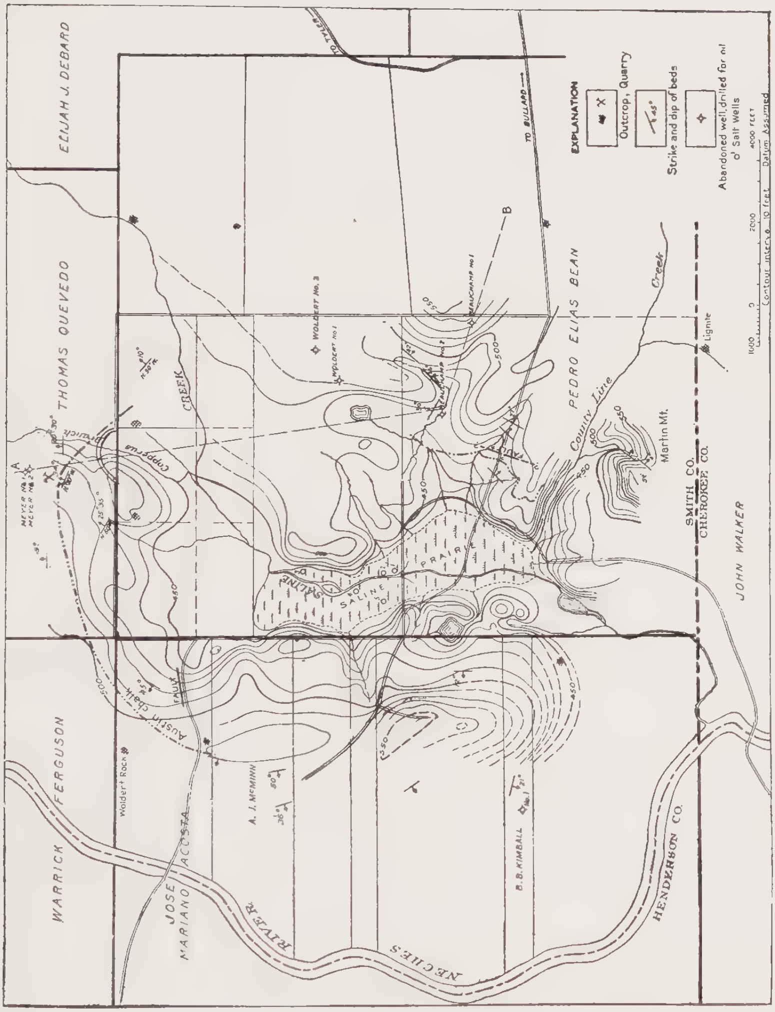

FIG. 7.—Topographic map of Brooks salt dome reproduced with changes from *Bulletin 736*. The Austin chalk is more widely exposed at the surface here than in any other salt dome. The central saline is an expansion of a creek valley, and is fed by salt water rising from artesian and ground waters some of which have come into contact with salt at a depth of 200–300 feet.

BROOKS SALT DOME

LOCATION AND HISTORY

Brooks salt dome (Fig. 7) is in the extreme southwestern corner of Smith County, 6 miles west of Bullard, 17 miles southwest of

Tyler, and 27 miles southwest of Steen dome. The saline prairie covers about 200 acres of the west half of the Pedro Elias Bean league.

Salt was evaporated here during the Civil War from salt water collected in shallow wells about 4 feet square and deep lined with wooden curbing. Seven furnaces were operated on the east side of the prairie and the production was 10 tons a day, 300 gallons of water making 1 bushel of salt.

Chalk was quarried from the north side of the dome and was used as flux in the iron ore smelters at Rusk, operated in 1885.

During 1903–4 five shallow wells were drilled for salt on the saline prairie and the deepest is reported to have encountered gypsum from 200 to 220 feet underlain by salt to 280 feet, the bottom of the hole. Distance from a railroad prevented exploitation of the salt.

Seven tests for oil were drilled by Dr. Albert Woldert and others of Tyler, Texas, during 1919–20 under the name Brooks Saline Oil and Development Company as described later.

TOPOGRAPHY

Brooks dome lies near the western edge of the wold formed by the outcrop of the Mount Selman ferruginous sandstones. The relief, like that at Steen dome, is as great as any in east Texas. The elevation of the saline prairie is probably about 430 feet and of the highest hills 550 feet.

The center of the dome is occupied by a barren prairie with a few low mounds covered by trees. The prairie is a lake in winter, a white, salt plain in summer. North and south of the prairie there is a swamp, that on the north being covered with marsh grass. Saline Creek rises northeast of the dome and flows through the prairie and into Neches River. Copperas Branch and County Line Creek and a number of short branches drain into the saline in radial manner.

High hills surround the dome on the west, northwest, southeast, and south sides. No circular drainage pattern has been observed outside these hills, but Neches River makes a large bend away from the dome and the hills on the west side slope gently to the river bottom.

GEOLOGY

Surface geology.—The formations represented at the surface are the Mount Selman (the type locality is 10 miles southeast), Wilcox (Carrizo sandstone and Indio formation), Navarro (?), Taylor, and Austin chalk. The shale on top of the ridge west of the prairie is probably Wilcox or Midway, not Eagle Ford or Taylor, as stated in

Bulletin 736. The Mount Selman formation caps the high hills on the north, east, and south, the Carrizo sandstone forms the sandy land on the east and north sides, the Indio has a narrow belt of outcrop and is exposed on the east side, and the Cretaceous formations surround the saline prairie except on the south where there are no exposures. Erosion on the west flank of the dome by Neches River has cut back the outcrop of the Eocene formations.

Chalk crops out on the east side of the dome in and near the road from Bullard to the saline. The exposure shows two beds, 5 and 10 feet thick, respectively, separated by 25 feet of green shale. Other streaks of chalk indicate that there is no massive bed. On the north side of the dome a small outcrop is found east of Copperas Branch. West of Copperas Branch and north of the settlement road there are two exposures, one at the quarry which is reached by a dim road through the trees, the other about 1,000 feet southwest of the quarry. The Meyer wells were drilled 1,500 feet north of the quarry and reached the chalk at 1,700 feet. At the quarry about 20 feet of chalk is exposed dipping N. 30° E. $<$ 34°, underlain and overlain by greenish shale. Another exposure showing a number of thin beds of chalk occurs northwest of the saline and another was found by M. I. Goldman in the southwest quadrant of the dome in a ravine.

Dr. Stephenson determined the age of the chalk from large fossils as Austin. Among the common fossils are *Baculites*, *Ostrea plumosa*, *Gryphaea*, *Inoceramus*, *Hamites* (?), and fish. Microscopic examination of the chalk from the quarry and from the Bullard road shows a Taylor microfauna.

Clays of green or yellow color, originally blue, surround the dome and occur both above and below the chalk. Their age is in part Taylor, as determined from samples secured at the chalk outcrop on the Bullard road but they may be in part Navarro. Fragments of *Inoceramus* are abundant. Shales under the chalk at the quarry have an upper Austin fauna according to A. L. Selig.

The Midway formation has not been recognized at this dome unless the shales on the ridge west of the saline are of this age.

The Indio formation is exposed in the gullies on the east side of the dome and on the ridge on the west side. These clays contain claystone concretions with cone-in-cone and the only fossil found by Dr.

Stephenson was a *Serpula* tube filled with glauconite grains. There are microscopic fossils indeterminate in age. The absence of exposures near Woldert Nos. 1 and 2 was unfortunately construed to indicate a normal stratigraphic section instead of surface wash underlain by cap rock and by salt at 309 feet.

The Carrizo sandstone is probably exposed on the Bullard road east of the south end of the saline and also north of the limestone quarry and north of the limit of the map, Figure 7. In soft sandstone 500 feet east of Beauchamp No. 2, Dr. L. W. Stephenson found *Cardium*, *Corbula*, *Venericardia*, and gastropods which may be Carrizo.

TABLE IV

NAME	SIDE DOME	DEPTH IN FEET				WHY ABANDONED
		Cap Rock	Salt	Chalk	Total	
Wells of 1903	Center	200	220	....	280	In salt
Woldert No. 1	East	195(?)	309	....	429	In salt
Beauchamp No. 1	East	....	....	2,864	3,193	In "shale and gypsum"
Beauchamp No. 2	East	....	1,343	765	2,161	In salt
Woldert No. 2	East	572	840	....	850	In salt
Meyer No. 1	North	....	....	....	528	Lost hole
Meyer No. 2	North	....	2,744	1,684	2,769	In salt
Kimball No. 1	West	....	....	....	1,864	Lack of funds

Mount Selman iron ores cap Martin Mountain on the Smith-Cherokee county line and here they are underlain by glauconite sand containing abundant casts of spired gastropods. Ferruginous sandstones also cap the hill east of Beauchamp No. 1 and the hills near Meyer Nos. 1 and 2 but they are probably Carrizo sandstone. There is an outcrop of lignite on the county line southeast of Martin Mountain, but the stratigraphic position is uncertain.

Conglomerates cemented with hematite and limonite are found at the north and southwest ends of the dome as well as in the form of boulders elsewhere. They are believed to be younger than the Mount Selman and to have been formed from the iron ores of that formation.

Underground geology.—Table IV shows the wells which have been drilled and their depth in the order drilled: The logs were printed in *Bulletin 736.*

Correlation of the logs is shown in Figure 8. Microscopic examination of the cuttings from two wells for microfaunas have been made by Dr. J. A. Udden, of Austin, Texas, and by Miss L. L. Lane, but the material was cuttings and not satisfactory. Alexander Deussen examined the cuttings when the wells were drilled and advises the writer that both Woldert No. 1 and Beauchamp No. 1 reached the Austin chalk.

Beauchamp No. 1 cuttings were described by Dr. Udden in a report to Dr. Woldert, of Tyler, but the writer does not have this interpretation on the age of the material. The well starts in red sand, and lignite of the Wilcox was found at 98 feet. Lignite is reported to a depth of 1,460 feet, sand to 1,250 feet, and silty clay with some sand to 1,500 feet. Limestone fragments were found at 1,285 feet, 1,460 feet, from 1,590 to 1,620 feet, 1,860 to 1,870 feet, 2,010 to 2,040 feet, 2,110 feet, 2,884 to 2,924 feet; chalk from 2,600 to 2,610 feet at 2,650 feet, from 2,740 to 2,770 feet. The first Foraminifera were noted at 1,745 feet and the next at 1,934 feet. They became abundant below 2,310 feet. *Inoceramus* fragments were found between 1,800 and 2,500 feet. Bentonite is reported from 2,010 to 2,060 feet. Sandy clay from 2,392 to 2,445 feet is underlain by clay containing *Ostrea congesta* (?). A fish tooth at 2,610 feet indicates Eagle Ford age. Alexander Deussen identified the Austin chalk in this well at 2,864 feet.

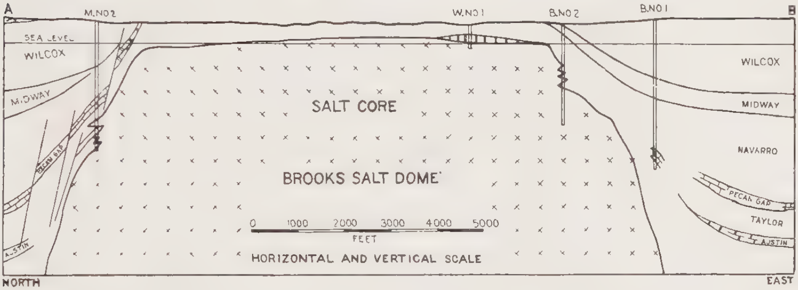

FIG. 8.—Cross-section of Brooks salt dome from north to east along the line *A–B* of Fig. 8 showing four of the wells drilled for oil (Meyer No. 2, Woldert No. 1, Beauchamp Nos. 1 and 2). Three of these tests found salt; two penetrated alternating beds of shale and salt. Pronounced squeezing (diapirism) of the formations has taken place around this dome, especially on the north side, so that the Austin chalk is brought to the surface and overlying formations are not exposed in nomal sequence.

Meyer No. 2 is located 1,500 feet north of the limestone quarry and reached the Pecan Gap chalk at 1,684 feet. Cuttings were described by Miss L. L. Lane in a report to Alexander Deussen dated February 23, 1924 and the following notes are made from that report.

TABLE V

Depth in feet	Character of Material
374, 523, 1,010, 1,128, 1,193, 1,361	Clay with some sand
1,516	Sand and clay
1,552	Limey shale with Foraminifera
1,650–1,701	Clay with prisms of *Inocerami* shells; a Taylor microfauna.
1,705	White chalky limestone, practically the same fauna.
1,539	Sandy clay, *Globigerina.*
1,722–1,739, 1,767	Clay and limestone, 12 species of Foraminifera of Taylor age
1,781–1,789	Clay, Taylor fauna, *Inoceramus*
1,995	Soft gray limestone, Taylor fauna
2,000–2,004	Sand and clay, prisms of *Inocerami*, Taylor fauna
2,012–2,136	Clay, same fauna
2,136–2,146	Gypsum
2,161	Core of rock salt
2,246	Clay and sand, same Taylor fauna
2,271–2,362	Clay, slight change in fauna
2,402–2,452	Sandy clay; typical Taylor association of forms reappears
2,453	Same, with impure coal.
2,536–2,551	Sand
2,605	Core of clay with glauconite grains, *Inoceramus*, 4 species of Foraminifera
2,706–2,716	Sandy clay, Taylor fauna

Miss Lane writes of the Meyer well: "It is impossible to tell where the Taylor fauna should disappear because of the evident mixture of material. The fauna changes slightly at 2,271 feet, but the typical association of forms reappears. Whether this reappearance occurred or whether the Foraminifera came down the hole cannot be determined." The sand at 2,386 feet in the Meyer well was called "Woodbine" prior to this microscopic study but it may be a stray sand. Miss Lane also examined a core of chalk from the Sinclair Oil and Gas Company Brooks well, on the B. S. Watts survey, 7½ miles northeast of Tyler, or 22 miles north of Brooks dome. This white chalky limestone was found from 3,195 to 3,310 feet and the exact depth of the core is not known. Miss Lane states: "The fauna does not correspond to that of the Austin or of the Taylor. Probably it represents a transitional phase." Miss A. C. Ellisor also examined this chalk and states: "This chalk contains a larger number of Foraminifera than is usually found in the typical Austin chalk and I believe it to be the Pecan Gap." These determinations indicate that the chalk in the Meyer well is probably Pecan Gap.

A normal stratigraphic section in the vicinity of the dome is believed to be as follows:

	Feet
Mount Selman formation	0– 100
Wilcox group	1,200
Midway and Navarro formations	1,900
Taylor marl, including Pecan Gap chalk	1,000
	4,200

Structure.—The diameter of the area uplifted at Brooks dome does not exceed 3 miles although the diameter of the salt is over 1½ miles at a depth of 500 feet and about 1¾ by 2 miles at a depth of 3,000 feet with the longer axis from north to south. The pitch of the edge of the salt core is not as steep as on the west side of Grand Saline. The amount of uplift of the Navarro-Taylor series which seems to surround the dome is about 3,500 feet and of the Austin, 4,300 feet. Squeezing (diapirism) has forcedthe older shales and the Austin chalk past the younger shales around the circumference of the salt core so that the Taylor is in contact with the Wilcox. Faulting may have aided this squeezing in the southeast quadrant, but the underthrusting of fragments of formations is not as notable as at Palestine dome.

KEECHI SALT DOME

LOCATION AND HISTORY

Keechi salt dome, named from Keechi Creek and not to be confused with the town of Keechi in Leon County, is situated 7½ miles by road, 6 miles in an air-line northwest of Palestine, Anderson County, on the Montalba and Athens road. The center of the saline is on the W. A. Cook survey. This dome is 13 miles northeast of Butler dome, 6 miles northeast of Palestine dome, 30 miles southwest of Brooks dome, 55 miles southwest of Steen dome, and 60 miles south of Grand Saline.[1]

This salt dome is not a conspicuous topographic feature because there is no central lake or barren prairie and no "race track" of barrens around the partly circular drainage. It was described by E. T. Dumble in the *Second Annual Report of the Texas Geological Survey*, in 1891, but it was not rediscovered until 1915 and then by W. I. Sims and L. C. Chapman. It was visited by O. B. Hopkins and by the writer in 1916 and described briefly by the former in Bulletin 661 of the United States Geological Survey. The topographic map of the dome (Fig. 9) was made by the writer in 1924 prior to the completion of the new concrete highway, but this is shown running in an almost straight line across the dome. Exposures are abundant at the side of the old road and all references are to that road.

Salt has never been evaporated here and the only evidence of salt, except for sparse vegetation and a small salt lick in the flat creek valley, is its discovery in the Producers Oil Company's well. The salt must be at a greater depth than in the other interior domes.

Five wells are drilled on the south side of the dome in 1916–17 by the Producers Oil Company (the Texas Company) on the Barrett and Greenwood land. The first had a showing of 8° Baumé gravity oil at a reported depth of 1,686 feet which might have made a well.

TOPOGRAPHY

Keechi dome is situated about 2 miles west of the Mount Selman escarpment. Dissected ferruginous red sandstones and weathered glauconite beds of the Mount Selman formation and, locally, hard beds in the Carrizo sandstone, produce a relief of 100 to 150 feet. The topographic map, based on mean sea level as datum, shows the intricate character of the topography. Salt Fork of Keechi Creek flows through the northern half of the central core of the dome in a broad valley and along its floor are a few semi-barren patches which are salty in summer. Keechi Creek, and its headward portion called Spring Creek or Wagoner Branch receives the drainage from the

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[1] Evidence of an uplift which may prove to be a salt dome has been discovered by M. A. Davey along the Neches River about 5 miles east of Neches, Anderson County, and 15 miles east of Keechi dome.

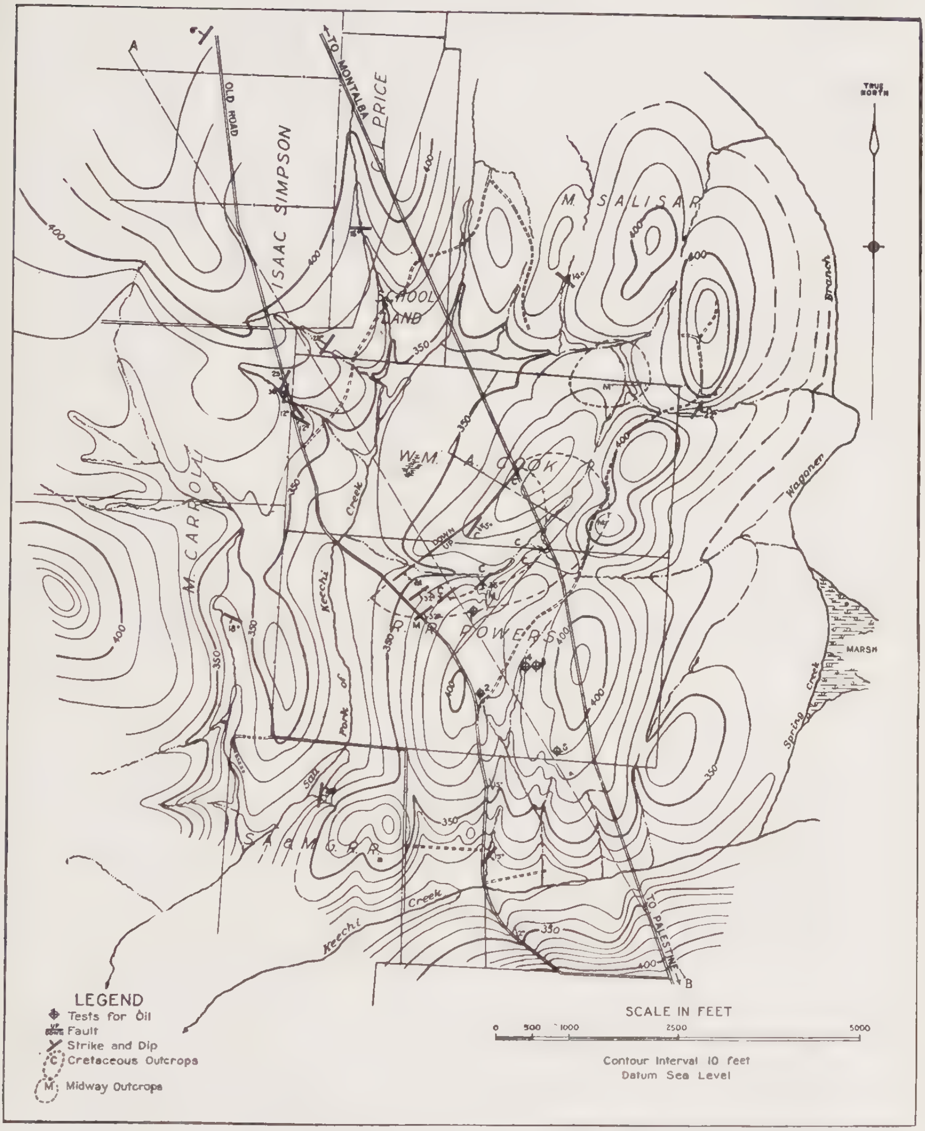

FIG. 9.—Topographic map of Keechi salt dome showing the fault through the center of the dome with Pecan Gap chalk on the south side thrust upward in contact with the Wilcox. Owing to the preservation of the original roof of the salt core, there is no conspicuous central saline. Circular drainage is enveloping the dome. The northernmost well, Barrett and Greenwood No. 1, had a showing of oil which led to the drilling of four additional tests.

northeastern part of the dome and flows in a semicircle around the western side of the dome. On the southwestern side it is joined by Salt Fork and farther west by drainage from the west side of the dome. The center of the structural dome occupies the area between Salt Fork and two tributaries which almost surround the rounded hill on which the conspicuous fault is located. This is the only Texas salt dome in which the original strata can be identified over the top of the dome.

Springs, which are characteristic of salt domes, are not conspicuous. There are springs along Salt Fork and along the valley of Keechi Creek, which cause boggy, grassy flats and a marsh on the southeast side of the dome. Mineralized springs were not noticed, but several dug wells have found salty water. A small marsh is situated on the broad, flat area south of Salt Fork and north of the fault. The hills north and west of Salt Fork do not show influence of steep dips. Those south and east rise more abruptly on the side toward the center of the dome and slope gently in the direction of the steeply dipping rocks beneath. The outer rim of hills south of the dome has a steep slope toward the dome.

GEOLOGY

Surface geology.—Keechi presents the unusual feature of a central fault of considerable magnitude which brings the Taylor chalk and clays on the south in contact with the Wilcox beds on the north. This fault was not noted in the earlier examination of the dome by Hopkins.[1]

North of the fault the outcrops for over a mile have been mapped as Wilcox because the shales at the fault look like Wilcox shales and because the occasional ironstone concretionary beds in the exposures along the highway are similar to those in the Wilcox. Lime nodules $\frac{1}{4}$ inch in diameter are very abundant in the outcrops along the road. Yellow Midway shale containing pebbles of calcareous mudstone filled with cone-in-cone structure are exposed in the eastern part of the Cook survey and also a few hundred feet north of the northeast quarter of that survey. Unquestioned Wilcox crops out farther away, overlain by the Carrizo sandstone.

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[1] The fault is mentioned by W. G. Matteson, *Amer. Inst. Min. Engrs., Bull. 134*, 1919, p. 445.

South of the fault yellow, waxy shales containing thin lenses and fragments of yellow and white fossiliferous limestone containing *Ostrea* are tilted steeply to the southwest. The limestone is blue where fresh. A new chalky limestone exposure was made in excavating for the concrete highway. The age of the limestone and chalky limestone is probably Taylor. Alexander Deussen remembers collecting an *Exogyra ponderosa* of Taylor age in this general area several years ago. Microscopic study of the limestone and chalky beds by A. L. Selig show an abundant basal Taylor microfauna. He correlates the chalk with that at Brooks dome.

Shale beds are continuous from the Taylor southward across a small valley tributary to Salt Fork and are exposed in the side of the old highway on the north facing hill. In the ploughed field northwest of Producers Oil Company well No. 1 two lenticular beds of chalk each about 2 feet in thickness crop out south of the yellow limestone blocks, surrounded by the same yellow clays. White chalk was observed several years ago by Alexander Deussen and L. C. Chapman ½ mile northeast of this outcrop and the microfauna at that locality is either Midway or Navarro, probably Midway.

South of the chalk and also on its strike both northeast and southwest yellow Midway shales are found in what appear to be continuous, unbroken exposures. Faulting must be concealed in the weathered outcrops and the entire section is not exposed.

Dr. L. W. Stephenson identified fossils for O. B. Hopkins as belonging to the *Exogyra cancellata* subzone of the *Exogyra costata* zone which constitutes the lower part of the Navarro formation. These were collected from shales in the gullies 300 feet north of well No. 1, and also along the large east-west valley. He also identified fossils from the fields near these gullies and states that they came from the middle or upper part of the Navarro formation. The locality is evidently shale resting on the easternmost chalk. In the following list the first 6 forms are the Hopkins' collection, the next 14 forms the writer's collection from shale resting on the westermost chalk, identified by Dr. Stephenson in March, 1924. These chalk lentils and the overlying fossil bed are probably very near to the top of the Navarro according to the personal examination of Dr. Stephenson in December, 1924. The microfauna is Navarro, approximately the age of the Nacatoch of Louisiana according to A. L. Selig.

Nucula, cf. *N. eufaulensis*
Trigonia sp.
Plicatula n. sp.
Crassatellites sp.
Ringicula sp.
Baculites sp.
Cliona sp. (a sponge)
Unidentified corals
Leda sp.
Cucullaea sp.
Ostrea sp.
Trigonia sp.
Unicardium (?)
Crassatellites sp.
Anchura sp.
Unidentified gastropods
Nautilus sp.
Pachydiscus sp. (resembles a species from somewhere in Clark County, Arkansas)
Baculites sp.
Belemnitella americana (Morton)

Dr. Stephenson makes the following comments regarding the collection of March, 1924:

> The fossils from the south side of the Keechi uplift are mostly casts in a poor state of preservation. With one exception I have been able to identify them only generically, but the one identifiable species, *Belemnitella americana* (Morton), has, I think, a definite significance in correlation, and indicates the upper Navarro age of the containing bed. This species is fairly common in places in the upper part of the Navarro formation, and in beds of the same age in other parts of the Atlantic and Gulf Coastal Plain. The species has not, to the best of my knowledge, been found in beds older than the Navarro. Although this collection is poorly preserved, the condition of preservation appears to me to be the same as that of fossils from a horizon at the top of the Navarro southeast of Greenville, Texas, and I am inclined to believe that it actually represents that horizon.

The collection was made from the easternmost chalk and the identifications by Dr. Stephenson, dated April 30, 1924 of forms not found in the earlier collections are as follows:

Nemodon sp.
Exogyra costata Say (?)
Cuspidaria sp.
Gastrochaena americana Gabb (?)
Unidentified pelecypods
Gyrodes (2 species)
Turritella sp.

Midway Foraminifera have been found by D. C. Barton in the head of the gully north of well No. 1 and in the gully at the side of the old road west of this well. The first locality yielded an upper middle Midway microfauna, the latter locality an upper Midway microfauna overlain by the Wilcox sand. The shales excavated by the new concrete road in the south side of the dome and the shales north and east of these exposures are also Midway according to Dr. Stephenson and A. L. Selig.

Underground geology.—The Producers Oil Company wells on the Barrett and Greenwood land were a great disappointment to the land owners because great secrecy was maintained after the first well struck oil at 1,686 (?) feet and because no tests were made north of this well. An excellent showing of 8° Baumé gravity oil was found, but the log of the well records sand at 1,647 feet and fails to mention a showing either then or at 1,686 feet. Dr. J. A. Udden examined cuttings from well No. 4 and wrote Mr. A. G. Greenwood on August 25, and November 14, 1917 that it was drilling in the Eagle Ford or Woodbine at a depth of about 2,400 feet.

A tentative correlation of well logs has been made, but the identification of formations is a guess. Well No. 1 penetrated chalk from 545 to 560 feet. No. 2 reports chalk from 952 to 964 feet, and No. 3 chalk from 1,111 to 1,140 feet. These may be the same. This thin bed is near the base of sandy series of Navarro age which must include the Nacatoch sand. Several beds of chalk separated by shale underlie the Navarro and must be of Taylor age. The first chalk of Taylor age, the Pecan Gap, crops out along the fault, as stated above, and is probably the first chalk found in each well. The chalky series is 700 to 800 feet thick and can include the Austin only if 700 feet of Taylor section is missing. The age of the persistent sand series under the chalk is Taylor (Wolfe City sand?) if all the chalk is Taylor; otherwise it may be Blossom. The "lime, gypsum, and packed sand" 900 feet below the top of the Pecan Gap has more nearly the normal interval of 1,200 feet to the Austin, but Dr. Udden found fish teeth in this series which seem to indicate Eagle Ford age. Such an abnormal thinning of the section would indicate squeezing (diapirism) or faulting near the salt core (Fig. 10.)

Salt was found by well No. 1, as an apophysis of the main mass 660 feet thick underlain by sandy beds which may also be of Woodbine age. The well was drilled into salt again and stopped in it. It is unfortunate that these wells were not tested more carefully and drilled deeper.

Table VI is a tentative correlation of the Barrett and Greenwood wells:

Roeser Petroleum drilled two wells near Montalba and about 5 miles northwest of Keechi dome in 1922–24 on the Via and Brooks-Auld farms to depths of 4,331 and 4,165 feet, respectively, and in July, 1924 drilled a twin to the former to 4,411 feet. Miss Ellisor found a Taylor microfauna in cuttings from the Brooks-Auld well from a depth of 3,600 to 4,100 feet. From a microfaunal study of cores F. X. Bostick identified Pecan Gap chalk from Brooks-Auld well at 3,424 feet.

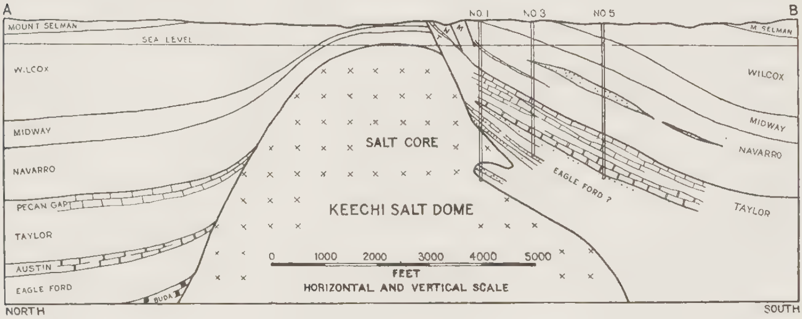

FIG. 10.—Cross-section of Keechi salt dome from north to south along the line *A–B* of Fig. 9 showing how the salt has elevated and faulted the south half of the dome. More faulting has taken place than is shown. This is the only interior salt dome in Texas where the original roof of the salt core is preserved in place.

In 1925 Roeser Petroleum drilled two more wells. Brooks-Auld No. 2, 250 feet east of No. 1, had Pecan Gap chalk at 3,399 feet with a Taylor microfauna underlain by a thick shale series with selenite crystals and several sandstones. The sandstones are of Taylor age and the lower part of the shale, Austin. Hard white chalk like that at Palestine salt dome was found from 4,620 to 4,820 feet, and is called Austin. Eagle Ford fossils were found by Miss Ellisor in 30 feet of black shale under the chalk. Dry sand from 4,850 feet to 4,895 feet was underlain by more black shale to 4,925 feet with an Eagle Ford fauna. The oil sand at 4,386 feet in the Via well was not found in this well. The other well, Daniels No. 1, 12 miles west northwest of Montalba on the Chas. Gilmore survey had Pecan Gap chalk at 2,827 feet and Taylor and Austin (?) shale from 3,250 feet to below 4,090

TABLE VI

	No. 1 El. 385	No. 2 390	No. 3 387	No. 4 380	No. 5 390
Sandy series, Wilcox (?)					0 – 221
Shale, Midway, Navarro		0– 469	0– 486	0– 426	221 –1,332(?)
Sandy shale, Navarro, Nacatoch in part (?)	0– 583	469–1,129	486–1,194	426–1,200	1,332(?)–1,886(?)
Shale, Navarro	583– 951	1,129–1,592	1,194–1,566	1,200–1,537	1,886(?)–2,091
Chalk with shale breaks, Pecan Gap at top	951–1,647	1,592–2,140	1,566–2,200	1,537–2,247	2,091 –2,888
Sandy shale; oil, gas, salt water, Wolfe City (?) or Blossom (?)	1,647–1,792 (oil 1,686?)	2,140–2,297 (gas 2,142?, water 2,257)	2,200–2,424	2,247–2,407 (gas 2,314, water 2,341)	2,888 –3,048
Lime and "gyp," Austin (?)	1,792–2,032		2,424–2,656	2,407–2,447 (fish teeth)	
Sand, sandy shale	2,032–2,162				
Salt	2,162–2,822				
Heavy oil sands	2,822–2,899				
Sandy shale	2,899–3,091				
Salt	3,091–3,170				

feet with Austin chalk from 4,090 to 4,300 feet. Brooks-Auld No. 2 found salt water, oil, and gas in the Woodbine sand from 5,206 to 11 feet and was abandoned at 5,231 feet. The Daniels well had salt water in the Woodbine sand from 4,963 to 5,010 feet, the total depth.

The section of Brooks-Auld No. 2 is interpreted as follows:

	Feet
Mount Selman and Wilcox	1,575
Midway, Navarro, and Taylor	2,380
Austin shale and chalk (part Taylor?)	865
Eagle Ford	

The interval between the top of the first (Pecan Gap) chalk and the Taylor water sands agrees so closely with the interval in the Barrett and Greenwood wells that the sands are believed to be the same. The Producers Oil Company wells on the Southern Pine Lumber Company and on Royall and Davey fee near Jarvis, in Anderson County, and the Atlantic Oil Producing Company's well at Ironton, Cherokee County, had a similar section. The first well appears to have reached the Pecan Gap chalk at 3,200 feet and to have stopped in the Taylor section at 4,346 feet. Several sands are reported in the Taylor. The Atlantic well had the Pecan Gap chalk at 3,765 feet. The Colliton Syndicate Clapp well 5 miles northwest of Ponta in Cherokee County is reported to have had the Pecan Gap chalk at 3,189 feet and a showing of oil in a sand in the Taylor at 3,567 feet and salt water at 4,242 feet. The showings of oil in this Taylor series in the Via, Barrett and Greenwood No. 1, and Colliton wells indicates a producing horizon above the Austin chalk which may prove commercially productive. The Woodbine sand may be found at a normal depth of about 5,300 feet, but this formation does not occur on the Sabine uplift and may not be found in the trough of the east Texas geosyncline. The Eagle Ford holds promise of commercially productive sands.

Several new wells will be drilled in 1926 by the Navarro Oil Company, the first being near Barrett and Greenwood No. 1.

Structure.—Keechi dome interrupts the normal southeast dip of 40 to 80 feet to the mile over an area over $3\frac{1}{2}$ miles in diameter with a salt core which may be 4,000 feet long from northeast to southwest and 3,000 feet wide. The amount of uplift of the oldest strata (Taylor) exposed at the surface is 3,500 feet. The steepest exposed dips are 45° and those at the margins of the map, Figure 9, 1½ miles from the center of the dome, are 2°.

Faulting is the conspicuous feature of this dome. A fault with a throw of about 2,000 feet cuts across the dome along the major axis as stated above in a N. 50° E. direction. The line of faulting is sharply marked on the surface for about 1,000 feet by an abrupt change in the color of the soil in ploughed fields as well as by a steeply tilted bed of yellow limestone on the south side in contact with Wilcox clay and by numerous veins of calcite some of which show casts of slickensides.

Other faults, both radial and tangential, separate the chalk lentils from the Midway shales on the south side of the dome a short distance northwest of well No. 1 because the chalk appears in a very limited outcrop. Calcite marks one possible fault line near the chalk. Faulting, or rather underthrusting, may bring up the Midway cone-in-cone material on the northeast side of the dome, because part of the normal sedimentary section is absent around these inliers.

Preservation of the original roof over most of the salt core with no evidence of subsidence is characteristic of the more deeply buried domes.

PALESTINE SALT DOME

LOCATION AND HISTORY

Palestine salt dome (Figs. 11 and 12), named and described by E. T. Dumble and later by O. B. Hopkins, is in Anderson County on the Elias G. Myers survey, 6 miles south of west of Palestine and 4½ miles east of Trinity River. It is on the line between Butler, Keechi, and Steen domes and is about 6 miles distant from each of the first two. Palestine dome is the largest of the Texas interior salt domes and uplifts the strata over an area over 4 miles in diameter.

This dome was formerly called the "Salt Works" because the Palestine Salt and Coal Company has made salt here since 1904. Salt is obtained from shallow wells as described later. It was evaporated here in small quantities in kettles during the Civil War. No deep wells have been drilled in this vicinity. Mr. A. L. Bowers drilled a well near Tucker, 3½ miles south of the dome, to 2,330 feet.

A lignite mine was opened $1\frac{1}{4}$ miles northeast of the dome in 1923 and three seams each $7\frac{1}{2}$ feet thick are mined. The lignite is used at the salt works.

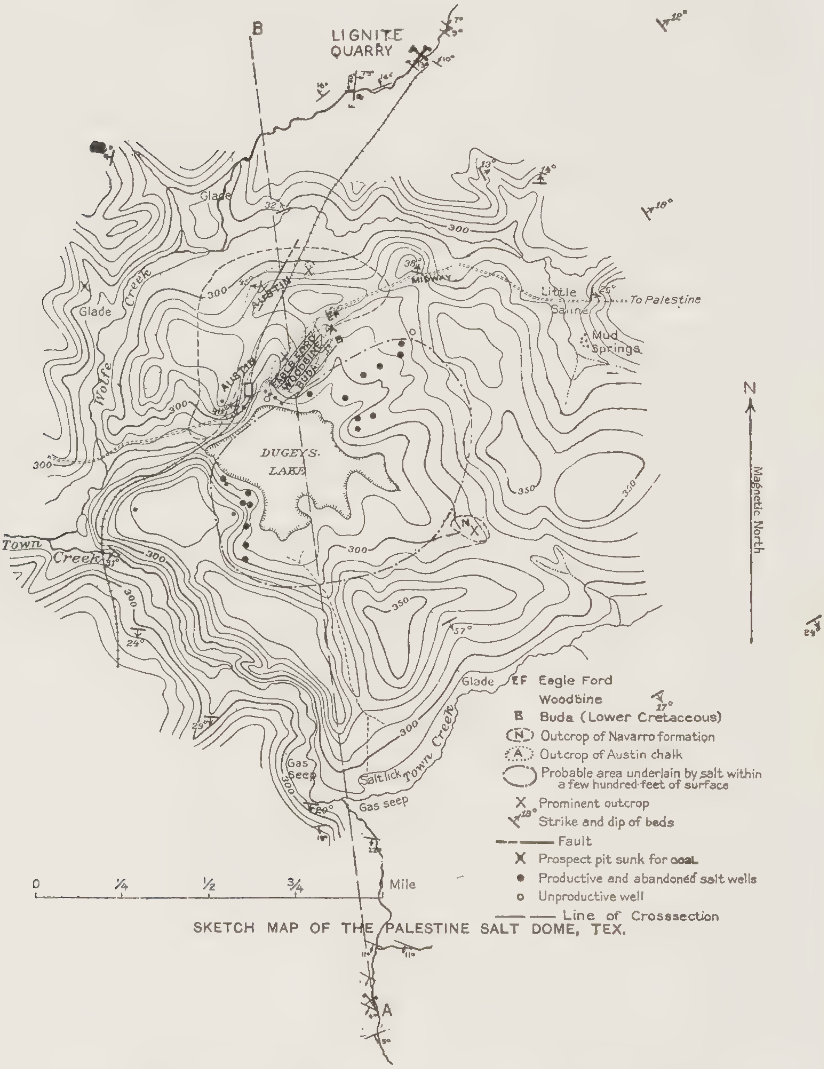

FIG. 11.—Topographic map of Palestine salt dome from *Bulletin 661* with additions. The central saline (an artificial lake) is surrounded by two concentric circles of hills separated by a circular drainage system. Salt is mined by means of wells and is evaporated in the plant north of the lake. The older Cretaceous formations crop out north and northeast of the lake.

TOPOGRAPHY

Palestine dome is the best example in Texas of a central lake, Dugeys lake, surrounded by hills which are in turn surrounded by circular drainage. One hill on the east side separates the head of Wolfe Creek on the north from a branch of Town Creek on the south. In place of the almost circular barren saline "race track" around Butler dome and Price's dome in Louisiana, there are swampy prairies and one real saline. Dugeys lake when visited by Dumble in 1891 was a small pool of water in winter only and was surrounded by a broad saline. The present lake, which is approximately ½ mile in diameter with a maximum depth of 4 feet, was formed by the construction of the railroad embankment which acts as a dam. Removal of salt from the top of the dome may have caused very slight subsidence.

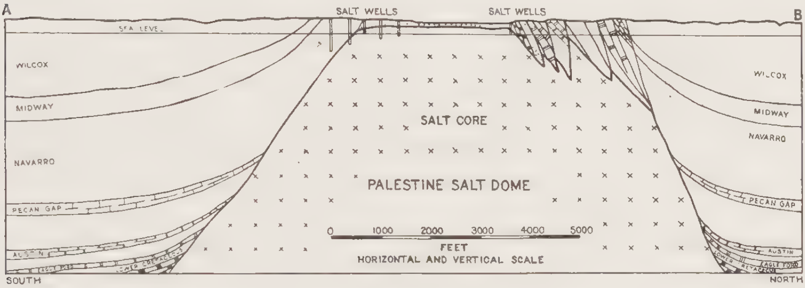

FIG. 12.—Cross-section of Palestine salt dome from south to north along the line *A–B* of Fig. 11 showing a large area of uplift owing to the conical shape of the salt core. Fragments of Lower Cretaceous limestone, Woodbine(?) sand, Eagle Ford limestone, and Austin chalk have been torn off by the intrusion of the salt and thrust upward about 1 mile in the form of blocks, the truncated edges of which are exposed on the north and northeast sides of the dome. This underthrusting illustrates the enormous force accompanying the intrusion of a core of salt through a vertical distance of 1¼ miles or more.

Hopkins' topographic map (Fig. 11) shows that the elevation of Town Creek is about 275 feet, that of Dugeys lake 280 feet, the inner hills 340 to 350 feet, the outer hills over 350 feet. Trinity River at the mouth of Town Creek is about 200 feet above sea level. The dome is near the northwestern edge of the cuesta or wold—the Nacogdoches wold[1]—formed by the iron ore beds of the Mount

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[1] Alexander Deussen, *U. S. Geol. Surv. Water Supply Paper 335*, p. 16.

Selman and this cuesta has an elevation of 500 feet within a few miles of the dome.

Little Saline, on the road to Palestine northeast of the salt works, is the most barren area around the course of the circular drainage. The steep northeast dip in the top of the salt core, as proved by wells east of the works, indicates that Little Saline and the other springs are fed by saline water which rises from salt water-bearing sands along their outcrops or else along faults or joints and not from the salt core. Many other springs are found along Wolfe and Town creeks.

Gas seepages are very numerous along Town Creek. The gas rises with the artesian flow of water and does not indicate the presence of gas in commercial quantities. An analysis of the gas given by Hopkins shows a high content of nitrogen and low content of carbon dioxide.

Mud volcanoes and mud springs in the process of building small domes may be observed on the southeast side of Little Saline. Gas bubbles rise with the water through the soft blue mud. A pole may be pushed down over 6 feet in these craters which vary from 1 to 3 feet in diameter.

GEOLOGY

Surface geology.—A greater number of formations crop out at this dome than at any other in the United States. These are: the Mount Selman, Carrizo, Indio, Midway, Navarro, Taylor, Austin, Eagle Ford, Woodbine (?), and Washita (Lower Cretaceous). This remarkable section is accounted for by the upthrust of the salt mass breaking off blocks of the older formations and thrusting them past one another in advance of and at the side of the salt core (Fig. 12). Fragments, only, of the formations below the Wilcox group are exposed and these fragments dip very steeply. The fault planes and the softer beds are not exposed and the details of the underthrusts can only be inferred. These blocks may correspond to the "breccia" of older rocks described on the top of several Roumanian salt domes. The Cretaceous is normally exposed 40 miles west of this dome.

Limestone below the Woodbine was not mentioned by Hopkins and was shown the writer by Mr. M. A. Davey, of Palestine. It is a hard, dense white rock which can be fractured with difficulty and is very different from the brittle Austin chalk. It contains casts of fossils, a small, smooth *Exogyra* sp. and an impression of an ammonite which appears to be a Lower Cretaceous form. According to Dr. L. W. Stephenson and Miss L. L. Lane (personal communication) it is probably Buda, the highest formation in the Washita group of the Lower Cretaceous. About 25 feet of limestone is exposed on the south side of the hill south of the Woodbine sand. Evidently it was formerly in contact with the salt, because nearby salt wells find salt at about 150 feet overlain by secondary deposits.

Woodbine sand is not found in any other inlier in east Texas or north Louisiana. The outcrop forms a ridge on the south side of the hill east of the salt works and is made up of 20 feet of pure, hard, gray to yellow friable sandstone with low iron content. It would make an excellent oil sand. The strike is N., 30° E., and dip 46° NW. Poorly preserved interior casts of pelecypods can be found by breaking open the sandstone. These have been identified by Dr. L. W. Stephenson as *Ostrea* sp. and *Modiolus* sp. ("poorly preserved, but closely resembles a species found in the Woodbine near Arlington, Tarrant Co."). Dr. Stephenson remarks: "So far as the evidence goes it tends to confirm the Woodbine age of the containing sandstone, but I do not regard this as very strong evidence. *Modiolus* has a long range and species of different ages have a general similarity in appearance." It is possible that this is one of the sandstones in the Eagle Ford found by Roeser Petroleum at Montalba.

Eagle Ford limestone overlies the Woodbine (?) sand in the ridge southeast of the salt works and has an exposed thickness of about 5 feet. The limestone is separated from the Woodbine sand by a few feet of rocks which are not exposed, but it is overlain directly by the Austin (Annona). Fossils are abundant and may be collected under one of the small houses nearest the salt works. Dr. L. W. Stephenson identified those collected by Hopkins as of Eagle Ford age.

Another locality was found on the main highway $\frac{1}{3}$ mile east of the salt works. Eagle Ford microfossils were identified by A. L. Selig in shale from a dug well between the Salt Works and the northern block of Austin chalk, and west of the railroad spur to the lignite mine.

Austin chalk forms the south side of the hill west of the plant and crops out on and near the road to Palestine north and northeast of the Eagle Ford. It also occurs on a hill $\frac{1}{3}$ mile north of the works and is well exposed in cuts in the railroad to the lignite mine. The duplication of outcrops is due to faulting and a thickness of over 25 feet of any bed is difficult to prove. The chalk is massive, brittle, fractures irregularly, and is gray where freshly quarried but becomes white on exposure. The strike is in general N. 15°–30° E. The dip 40°–50° NW. The availability of the chalk has led to its wide distribution for road metal and abandoned mud holes provide interesting "outcrops."

Identification of the Austin (Annona) chalk by means of several species of *Inoceramus* was made by Dr. Stephenson. Two very large specimens presented to the Southern Methodist University at Dallas were identified by Professor E. W. Shuler as resembling *Inoceramus vanuxemi* Meek and Hayden. Dr. Stephenson identified *Inoceramus* sp., *Ostrea* sp., and *Spondylus* sp. from the writer's collection. He remarks: "The form identified as *Inoceramus* sp. is somewhat suggestive of *Inoceramus labiatus* Schlotheim of the Eagle Ford shale, and for this reason I should regard the containing chalk as more likely to be the typical Austin chalk than one of the higher chalks of Taylor age." Microscopic examination of the chalk, by Miss Lane, revealed a Taylor microfauna. The microfauna identified by A. L. Selig, both from the top and base of the chalk is upper Austin with a microfauna similar to that in the shales below the Blossom sand at Ben Lomond, Arkansas, which were considered by Dr. Stephenson as of Austin age. No Pecan Gap chalk has been found.

Navarro shales have been identified over an area of about 300 acres north of the salt works and of the southernmost Annona chalk. Those shales probably almost completely encircle the lake, but sand washed from the Wilcox mantles the shale lowlands. A fossiliferous locality was found by Hopkins of the south end of the lake. Lower Navarro fossils from the *Exogyra cancellata* subzone of the *Exogyra costata* zone were identified by Dr. Stephenson.

Midway shales crop out on the Palestine road midway between the Eagle Ford locality and Little Saline. They undoubtedly surround the dome on the inside edge of the circular drainage.

The Wilcox group surrounds the dome and is very steeply tilted away from the center. Most of the outcrops are on the inner side of the outer row of hills and the dips ¾ mile from the center of the uplift vary from 20° to 30°. The steepest are on the outer side of the inner row of hills and a dip of 57° was found by Hopkins southeast of the lake.

The Wilcox consists here as elsewhere of sandy clays with sands and lignites and thin ironstone concretionary beds. No calcareous beds have been observed. At the lignite mine 1¼ miles northeast of the lake the three beds of lignite, each 7½ feet thick, are separated by 25 to 30 feet of sandstone and shale. A limonitic sandstone filled with casts of pelecypods occurs 45 feet above the highest lignite. This bed outcrops in a branch 300 feet northeast of the mine. The dip is 11° N. 80° E. The fossil casts have been identified by Dr. Julia A. Gardner of the United States National Museum, as: *Venericardia planicosta* Lamarck, *Cardium* sp., cf. *C. hatchitigbeense* Aldrich, *Corbula* sp. ind., *Bulliopsis* sp. cf. B. *choctawensis* (Aldrich), *Turritella* sp. cf. *T. pleboides* Vaughan. The age is probably upper Wilcox (Carrizo).[1]

The Mount Selman formation consisting of fossiliferous glauconitic sands overlain by iron ore, forms high hills 3 miles from center of the dome which have been slightly affected by the uplift according to Hopkins. Chapman, on his unpublished map of the dome, shows the lignite which is being mined and a similar bed on the south side of the dome to be highest bed in the Carrizo sandstone.

Underground geology.—Salt wells have been drilled on the northeast, west, and south sides of the lake. The shallowest salt is found at 122 feet in a well located a few hundred feet south of the Woodbine sand ridge. It is equally shallow on the west side of the lake in the well nearest the lake. The cap rock of gray, hard limestone, increases rapidly in thickness from 9 feet at the western shore of the lake to 32 feet in the wells farthest away. On both sides of the lake several wells have found very thin cap rock and have formed craters. The formations above the cap rock are sand and shale, either recent wash deposits or subsided Eocene sediments. On the east side of the lake the salt and shale were too intimately mixed for the brine to be used. Other wells were drilled nearly as far east as Little Saline and they encountered salt at 200 to 225 feet, but the salt was not overlain by a water sand and the cost of pumping water into the wells was too great. The well farthest northeast was drilled 560 feet and found only streaks of salt. A well drilled in 1923 in the small valley south of the lake was abandoned at 700 feet without finding the main salt core. Wells a few hundred feet north found the salt at the normal depth. Two wells were drilled through the salt and found it about 400 feet thick, but they did not go deep enough to determine the possibility of deeper salt.

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[1] See J. A. Gardner, "Fossiliferous Marine Wilcox in Texas," *Amer. Jour. Sci.*, Vol. 7, 1924, pp. 141–45.

Wells are drilled to the cap rock, at 120 to 160 feet, casing is set, and then the well is deepened 100 to 250 feet in the salt. Water from a water sand under the cap rock flows into the wells, dissolves the salt, and the brine is forced by compressed air to the plant. One well produced salt for 20 years, but others have caved where the cap rock is thin. Production in 1924 was obtained from two wells drilled in 1923 at the south end of the lake.

The well on the west side of the lake, one location south of the northernmost well, found sufficient cap rock underlain by water sand ("salt sand") to be a good producer as shown by the following log, although the northernmost well had no cap rock.

Feet (depth)	
18	Surface sands and clay
58	Blue shale
64	Sandstone
91½	Limestone
110	Blue shale
121	Blue shale and lime
122	Calcite
161	Blue shale
167	Salt
197½	Blue shale
199½	Gypsum
211½	Salt sand
406	Salt

The output of salt is normally 120 tons daily. It is shipped in barrels, weighing 280 pounds and in sacks. Assuming a production of 100 tons daily since 1904 gives the amount of salt produced as

500,000 tons or a bulk sufficient to permit the surface to subside as much as 2 feet over an area of $\frac{1}{2}$ square mile.

The normal stratigraphic sequence may be judged from the Brooks-Auld No. 2 well near Keechi dome described above.

Structure—Underthrusting.—Palestine and Keechi domes exhibit complex faulting which can be accurately mapped only after very careful study. One of the faults is well exposed in the railroad cut northeast of the salt works. The faulting at Palestine is more complex than that shown at the surface in other domes and it represents a series of underthrusts arcuate in form of blocks of formations older than the Wilcox with repetition of outcrop of the Austin chalk and Navarro formation (Fig. 12). The thickness of the Upper Cretaceous section is about 3,200 feet, and slices from four formations, some of which must have risen 5,500 feet, are exposed in a horizontal distance of less than 1,000 feet. About 1,500 feet of Eocene has also been removed from the center of the dome. The presence of salt directly beneath the Washita outcrop illustrates the force of the thrust of the salt core $1\frac{1}{4}$ miles in diameter shattering the intruded strata and thrusting shreds of several competent beds through 3,000 to 5,500 feet in height and over an area 30,000 feet in diameter.

The salt core as well as the region in general has suffered extensive erosion. It may originally have sheared its way completely through the Cretaceous and have stood far above the level of the present lake with other shreds of Cretaceous since removed by erosion.

Study of the distribution of the Cretaceous and of the underthrusting at Palestine dome will prove that the amount of uplift of Cretaceous formations cannot be measured with the same facility as the amount of uplift of the Wilcox which surrounds the dome. Underthrust shreds of deeply buried formations may be carried upward long distances by the salt and may be thousands of feet above the point where the upturned edges of the formation completely encircle the salt core. This condition applies at Brooks and Keechi as well as at Palestine domes. Were it not for underthrusting the Navarro might be the oldest formation exposed at any dome. The apparent scarcity of the Midway may be due to underthrusting and squeezing (diapirism) of older formations past it.

BUTLER SALT DOME

LOCATION AND HISTORY

Butler or West Point salt dome (Fig. 13) is located near the southeastern corner of Freestone County 3 miles east of the settlement of Butler, 6 miles north of Oakwood, in Leon County, and 4 miles west of Bonner's ferry across Trinity River. It is near the eastern end and extends across the south line of the Simon Sanches

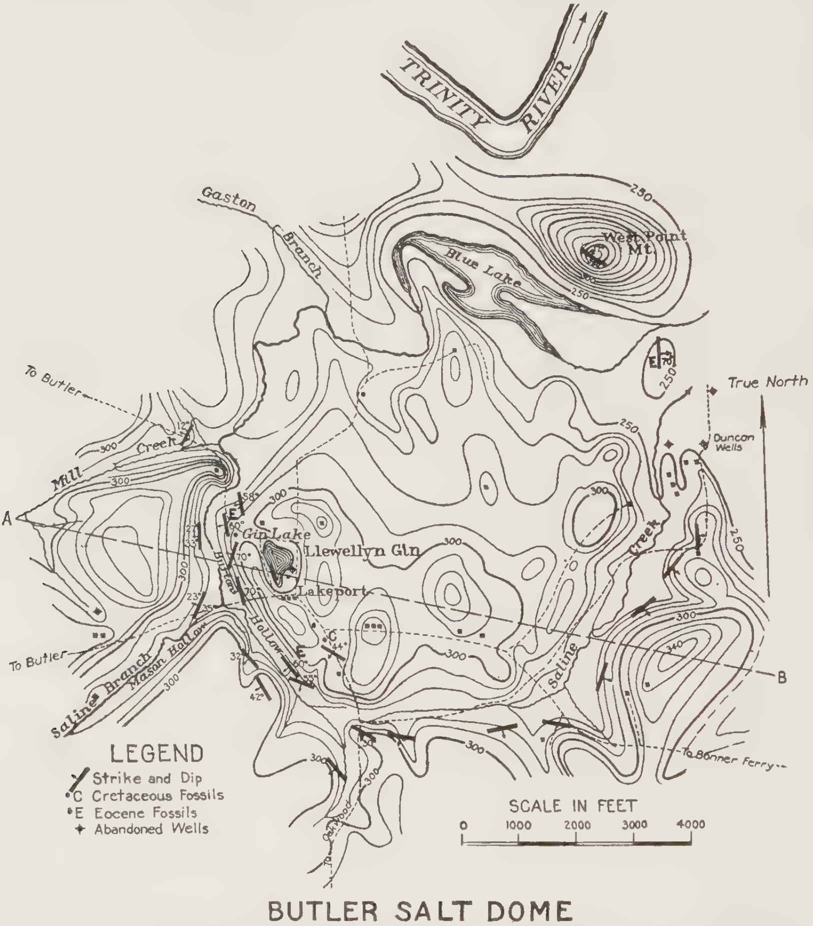

FIG. 13.—Topographic map of Butler salt dome showing a perfect example of a circular "race track" of barren saline prairie surrounding the dome. Radial drainage and springs supply the circular drainage. Llewellyn Gin Lake is a sink hole above the salt at the western edge of the salt core.

league No. 3. The name Butler, given by Hopkins, is from the nearby settlement and should not be confused with a settlement in Bastrop County by the same name. Neither is a post-office. West Point, the name given by Woodruff[1] and by DeGolyer, refers to a landing on Trinity River northeast of the dome when east Texas rivers were navigable. This name is lost except in local legend and is duplicated by a post-office in Fayette County.

Palestine dome is 6 miles northeast of Butler dome; Trinity River flows through the syncline between them, approaching within half a mile of Blue Lake, then making a conspicuous bend around the eastern side of Butler dome. The river is antecedent to the latest uplift of these domes.

Butler dome is topographically and geologically a type example of a salt dome with a central hill or mound surrounded by circular drainage in the form of a barren, saline "race track." Llewellyn Gin lake is on the west side of the central hill. The outer rim of hills is similar to that at Palestine dome, but the area affected by the uplift is probably only 3½ miles in diameter whereas at Palestine dome it is over 4 miles. The central salt core lies within the row of hills inside the "race track" and the diameter of the salt is probably 1 mile.

Salt has been evaporated in small quantities at the broad saline in the northeastern quadrant of the dome. The wooden curbings of the shallow wells dug to collect the salt water are still visible.

Several wells have been drilled to a shallow depth in search of oil as described below.

TOPOGRAPHY

The barren saline "race track" which surrounds Butler dome surpasses in extent and continuity that of any other dome. Circular drainage outlines Palestine dome and circular drainage with salines outlines Price's dome in Louisiana, but groups of trees separate the salines on Price's dome so that the circle is not completely barren. The diameter of the circle at Price's dome is slightly over ½ mile, at Butler dome almost 1½ miles. In both domes the drainage divide in the circle is so low and the sand covering the saline is so wet that it is imperceptible except in the driest weather.

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[1] E. G. Woodruff, *Bull. Southwestern (Amer.) Assoc. of Petroleum Geologists*, Vol. 1, 1917, p. 81.

Within the "race track" is the central "hill," or "mound"; a series of hills at Butler, a single hill at Price's. Sink holes are found on the hill in each dome; Llewellyn Gin Lake at Butler, and several small, dry sink holes at Price's. The maximum relief within the circle at Butler is 80 feet, at Price's 60 feet.

Outside the "race track" a rim of hills with steep slopes toward the saline surrounds Butler dome. Their relief is 70 to 80 feet above the saline, the same as the relief of the inner hill, with the exception of a monadnock of calcareous sandstone, called Rocky or West Point Mountain, which has a relief of over 100 feet. The other hills are composed of Wilcox sandy clays and outcrops are found along the base of the hills behind the line of springs.

Drainage of Butler dome is by Burton Hollow on the west and Saline Creek on the east, both emptying into Trinity River on the northeast. Burton Hollow, the larger creek, is fed by numerous springs and by radial branches flowing toward the dome. The source or the drainage is a gully on the Oakwood road and tributary branches are Saline Branch flowing through Mason Hollow, Mill Creek, and Gaston Branch Saline Creek rises in the saline prairie and is fed almost entirely by springs. Burton Hollow on the north empties into Blue Lake, a wide flat area covered by a shallow lake most of the year. Elevations with reference to sea level have not been determined in this region, but the assumed elevations on the map, Figure 13, must be approximately correct.

SPRINGS AND MOUNDS

Springs of fresh and of mineralized water characterize salt domes and commonly wells in the center of domes find undrinkable water. Contrary to usual conditions, water in shallow wells at Llewellyn Gin is potable. Salt, sulphur, iron, and alum are the minerals usually associated with the water. Many springs seep from the edges of the hills surrounding the saline "race track," others rise on the surface of the saline. Some have no pool of water, others form minature mud volcanoes, still others form pools of water surrounded by quagmires of unknown depth. One of the largest mineralized springs on interior salt domes is a strong sulphur spring in the center of Vacherie dome, Louisiana, where the sulphur odor permeates the surrounding woods. An important sulphur spring occurs at the foot of West Point Mountain near Blue Lake.

The origin of the water in most of the springs and in the sandy surface of the saline is from upturned water-bearing sands. Salt water sands are found at shallow depths in the Coastal Plain and the uplift and erosion of the domes truncates these sands and permits artesian flows. Strongly mineralized water usually rises through joints, fissures, or faults, from greater depths. Many salines not connected with structural uplifts derive their salty water from normal impregnation of salt in certain Eocene horizons.

Mounds, of the type well known in the Coastal region, are abundant on Butler dome. They vary in size from a few feet to 100 feet in length and breadth, in height from a few inches to 4 feet. The best example on any interior dome is a newly formed mound northeast of Blue Lake and southeast of West Point Mountain. In 1923 it was 2 feet high and 6 feet in diameter with sharply curved sides and a flat top. It was composed of yellow clay dry on the outer two inches but plastic beneath so that the mound could be shaken like a bowl of jelly. A pole could be pushed down for over 10 feet in the center and the mud squeezed the pole out again, yet no water ran out of the mound. Most of the mounds at this dome are formed by creep of water-saturated clay below springs on the edge of the saline, but the new mound and many others nearby rise on the flat saline and are caused by springs carrying more or less gas.

GEOLOGY

Surface geology.—The oldest known formation at Butler dome consists of clays which weather black or yellow in color and which contain a few rolled Cretaceous fossils. These are found with a few score small phosphate nodules at one place in the side of a gully southwest of the junction of the Bonner Ferry and Oakwood roads. These have been identified by Dr. Stephenson, as previously described by the writer, as of Upper Cretaceous age.[1] The microfauna is Cretaceous according to A. L. Selig. Rolled fossils and phosphate nodules occur also in the Navarro clays north of Barrett and Greenwood well No. 1, on Keechi dome, and therefore the Butler clays are probably of Navarro age. The center of the dome seems to be capped with red Wilcox sandy clays which obscure other outcrops.

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[1] *Amer. Jour. Sci.*, Vol. 49, 1920, p. 128.

The fossils collected in 1919 were *Cucullaea* sp., *Exogyra* sp., *Trigonia* sp., and *Cardium spillmani* Conrad (?). In a collection made in 1924 Dr. Stephenson and Dr. Julia A. Gardner identified *Inoceramus* sp., *Exogyra* sp., sharks teeth, and fragments of ammonites.

Above the Navarro and on the inner rim of Burton Hollow between the two roads to the southwest of Butler a bed of concretions which stands up conspicuously from the surrounding shales carries fossils of Midway age identified by Dr. Stephenson. They are obtained most easily near the north road from a few concretions in which the original shale has not been impregnated with limonite or contorted by cone-in-cones. Dr. Julia A. Gardner has published a list of 40 fossils from this locality.[1] The adjacent shales contain an upper Midway microfauna identified by A. L. Selig. The same bed of concretions can be traced around the southwest quadrant of the dome and can also be found southeast of West Point Mountain and northwest of the Duncan wells.

Typical Lower Wilcox (Indio) red, gray, and chocolate colored sandy clays containing limonite concretions and lignite beds form the hills surrounding the circular saline. The chocolate or lavender shales carry leaf impressions. The race track is eroded in the lower portion of this sandy shale series and the symmetry of the race track is caused by the circular outcrop of the same easily eroded bed.

Plant impressions were collected by O. B. Hopkins and also by F. B. Plummer in the lower part of the calcareous sandstone of Carrizo age which forms Rocky or West Point Mountain north of the dome. The locality is near the eastern end of the mountain. These collected by Hopkins have been identified by Berry as of Wilcox age.[2] This sandstone which is identical in appearance with the "limestone" at Steen Saline, was quarried in 1870 and used for the railroad abutments over Trinity River. Carrizo sandstone is not recognized elsewhere around this dome except in the bank of Trinity River at Bonner's ferry.

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[1] "New Midway Brachiopod, Butler Salt Dome," *Amer. Jour. Sci.*, Vol. 10, 1925, pp. 134–38.

[2] E. W. Berry, *U. S. Geol. Surv.*, *Professional Paper 131:* The forms are *Mespilodaphne coushatta* Berry?, *Palmocarpon butlerensis* Berry, *Proteoides wilcoxensis* Berry, *Sophora repandifolia* Berry?, and *Calatoloides eocenicum* Berry.

Underground geology.—Six shallow wells in search of oil have been drilled on and around the dome and their location is shown on the map, Figure 13. Three are on what was formerly the J. M. Duncan farm on the northeast side of the dome and were drilled to depths of 200, 700, and 1,220 feet, respectively. None of them reached salt. Two of them flow fresh water. A well was drilled at Llewellyn Gin and the casing may still be seen. It reached salt at about 312 feet and was abandoned in it at about 1,200 feet. Two wells were drilled west of the gin on the Cornwell farm to a depth of about 700 or 900 feet. Artesian water flows from the southernmost of the Cornwell wells.

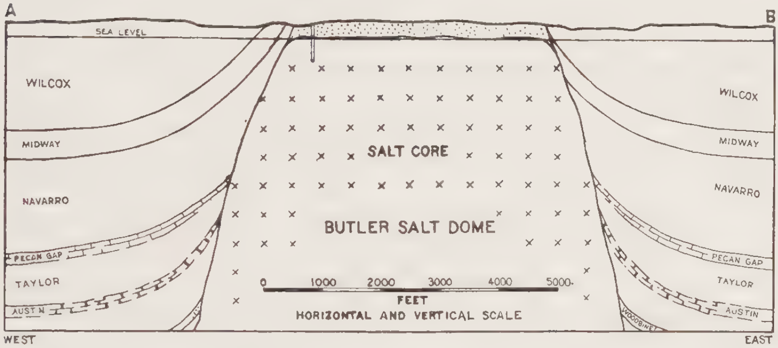

FIG. 14.—Cross-section of Butler salt dome from west to east along the line *A–B* of Fig. 13 with the salt core represented as an almost cylindrical plug.

Only a few deep wells have been drilled in this vicinity. The Mike Healy test on the McDaniel farm near Butler, 5 miles west of the dome, reached a depth of 4,000 feet, but the log does not record chalk near the base. The Keechi Petroleum Company well on the McKinnon farm, John Carson survey, in Leon County, 12 miles southwest of the dome, was completed with cable tools. The log reports chalk from 3,943 to 4,003 feet which is probably Pecan Gap. The Sun Company Worthy well at Donie had a chalk at 3,185 feet which may be Pecan Gap and stopped in Austin chalk at 4,186 feet. If these correlations are correct the normal section at Butler dome would have Pecan Gap chalk at about 3,900 feet, Austin at 4,900 feet, and Woodbine at 5,800 feet.

Structure.—The quaquaversal dips surrounding the dome have already been described. The steepest are 70° on the hills inside Burton Hollow. Those on the inner side of the outer rim of hills vary from 20° to 55°. The ferruginous sandstone on Rocky or West Point Mountain dips 17°. Faulting has not been observed and the uplift seems to be very regular.

The diameter of the circular saline is 7,500 to 8,000 feet, of the salt core 1 mile, and that of the area uplifted by the doming is probably 3½ miles. The edges of the salt core are probably steeply inclined as shown in Figure 14 because the area uplifted is not as great as at Palestine. If the oldest beds exposed by normal upturning are of Navarro age the amount of their uplift is about 2,500 feet. The lack of exposures within the outcrop of Cretaceous shales may indicate slight solution and subsidence of the top of the salt core besides that at the Gin lake. The red Wilcox soil now covering it may have washed in over either the Cretaceous or the dissolving salt, probably over the latter.

INTERIOR SALT DOMES OF LOUISIANA

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ABSTRACT

The eleven known interior salt domes of Louisiana, herein described, are distinct and separate from the Gulf Coast domes. They occur in an area of Claiborne Eocene exposures, on the east flank of the Sabine uplift, in the northwestern part of the state. They are distinguished from the common salines by characteristic salt-dome topography and other surface manifestations.

This paper lists the more important publications on the Louisiana interior domes, dating from Forshey, in 1850, to Harris, in 1910, and adds thereto much new information secured by recent drilling and by special investigations of the author and others.

All but one of these domes have been partially explored by drilling for oil and gas, but as yet no production has been found. The history, topography, and geology of each dome are described in detail.

INTRODUCTION

LOCATION OF SALT DOMES

The salt domes of Louisiana, based on the geographic distribution, are divided into interior and coastal domes. The coastal domes occur in a belt about 70 miles wide, bordering the Gulf of Mexico. The known interior domes, separated from the coastal domes by a district apparently lacking salt domes, are limited to a rectangular area on the east flank of the Sabine uplift, about 75 miles long and 35 miles wide, which includes most of Bienville and Winn parishes. The longest dimension of the rectangle extends from southern Winn Parish to the Vicksburg, Shreveport & Pacific Railroad in southern Webster Parish, and is parallel to the axis of the Sabine uplift.

Bistineau salt dome, in southern Webster Parish, is located in the northwest corner of the rectangle; Vacherie dome is on the line of Webster and Bienville parishes; Arcadia, Rayburn's, King's, and Prothro domes are in Bienville Parish; Coochie Brake, Cedar Creek, Winnfield Quarry, and Price's domes are in Winn Parish; and Drake's dome is on the line of Winn and Natchitoches parishes. The locations of the salt domes are shown in Figure 1 and Plate 5.

The Sikes dome, in northwestern Winn Parish, is probably a salt dome, although neither cap rock nor salt has been found. A well now being drilled in Sec. 15, T. 18 N., R. 7 W., Webster Parish, found the Upper Cretaceous at a depth of 570 feet, the top of the Lower Cretaceous probably at 978 feet, and anhydrite at 1,169 feet, indicating beyond reasonable doubt that it is on a typical salt dome.

SALINES

In addition to the salt domes described here, there are several localities which may, on further exploration, prove to be typical salt-dome structures. These localities, commonly known as "salt licks," or "salines," are usually barren, or nearly barren, spots where salt waters reach the surface from shallow depths. Sulphur water is found associated with the salines in some places. Characteristic salt-dome topography, steeply dipping beds, and outcrops of rock older than those usually found at the surface have not been recognized in these localities. The better known and most characteristic of the salines are listed:

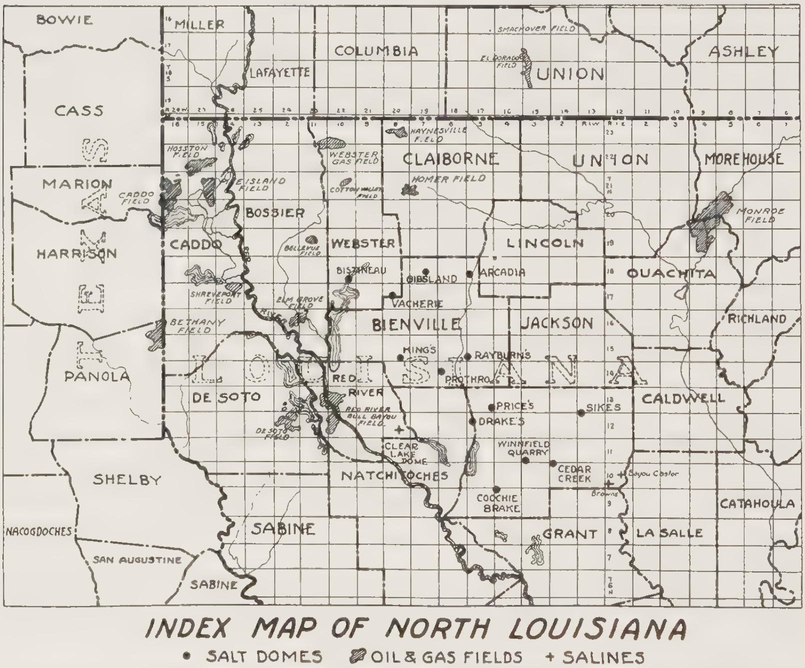


FIG. 1.—Index map of northern Louisiana and southern Arkansas showing locations of salt domes and oil and gas fields.

Bayou Castor Saline, in southeastern Winn Parish, about 3 miles

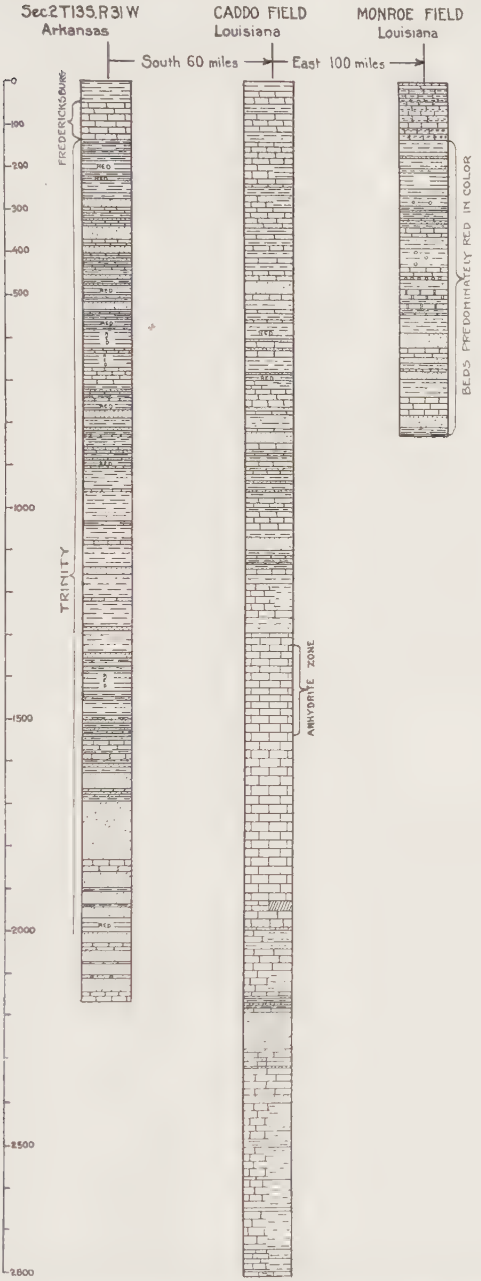


FIG. 2.—Lower Cretaceous sections showing relation of these beds in southwestern Arkansas, northwestern and northeastern Louisiana.

north of Rochelle; the salines cover portions of Secs. 15, 16, 21, and 22, T. 10 N., R. 1 E.

Brown's Saline, in southeastern Winn Parish, 18 miles southeast of Winnfield and 3 miles northwest of Rochelle, in Sec. 30, T. 10 N., R. 1 E.

Salt Springs, in southeastern Red River Parish, along Grand Bayou, in Sec. 22, T. 12 N., R. 8 W.; open saline with springs of weak brine and springs flowing sulphur water.

Clear Lake, in T. 11 N., R. 6 W.; salt and sulphur water in spring; gas emanations.

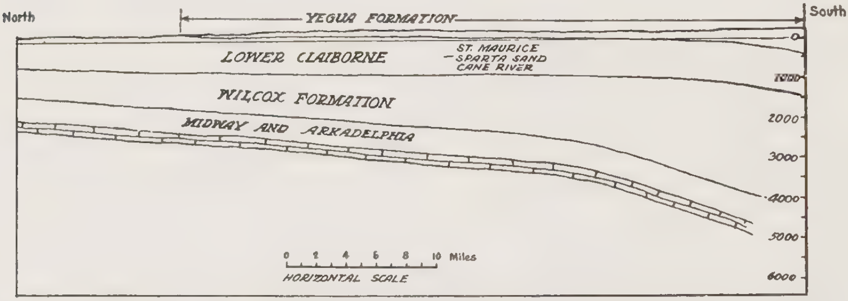


FIG. 3.—Diagrammatic section showing the southward thickening of the Wilcox formation.

SOURCES AND ACKNOWLEDGMENTS

Many references to the salt springs of northern Louisiana are found in the published accounts of the early travelers and explorers of this region. A very complete list of references is given by Veatch[1] and DeGolyer.[2] The first notable contribution to the knowledge of the geology of northern Louisiana was by Hilgard[3] in 1869 and 1873. The later publication contains the more detailed statement of the geology and the salines. Other investigators of this period were Hopkins, Lerch, and Vaughan.[4]

[1] A. C. Veatch, "The Salines of North Louisiana," *Geol. Survey of Louisiana, Report of 1902*, Special Paper No. 2 (1902), pp. 49–50.

[2] E. DeGolyer, "Origin of North American Salt Domes," *Bull. Am. Assoc. Petroleum Geologists*, Vol. 9, No. 5 (August, 1925), pp. 831–74.

[3] E. W. Hilgard, "Summary Result of a Late Reconnaissance of Louisiana," *American Journal of Science*, 2d Ser., Vol. 47 (1869), pp. 78–88; *Supplementary and Final Report of a Geological Reconnaissance of Louisiana*, New Orleans, 1873.

[4] See literature.

The most important period of investigation began in 1889 and continued to 1910. During this period G. D. Harris and A. C. Veatch, of the Geological Survey of Louisiana, mapped and described the geology of Louisiana. *The Salines of North Louisiana,* by A. C. Veatch, published in 1902, contains a very detailed and complete description of the then known salt domes of this region. The numerous publications by these authors are referred to elsewhere or listed in the bibliography.

In preparation of this paper the writer has spent considerable time in field work, mapping the topography and geology of the several salt domes with telescopic alidade and plane-table. He has collected and carefully examined all available data, such as well records, cores, and cuttings, and has used freely previous publications, for which credit is given in the proper places.

It is a pleasure to acknowledge the whole-hearted co-operation of the geologists of this region, who have generously furnished information, assistance in mapping, and valuable suggestions, and it is a regret that lack of space prohibits acknowledgment to each individual. The companies have been equally generous in furnishing available information. The writer is especially indebted to Francis X. Bostick for the examination and correlation of samples and cores from wells drilled on Arcadia and Vacherie domes, and for other valuable assistance, and to A. L. Selig, for examination and correlation of numerous samples from wells and outcrops, and for assistance and valuable suggestions too numerous to mention. L. W. Stephenson, of the U. S. Geological Survey, has identified many of the fossils collected from the salt domes. H. V. Howe, of the Louisiana State University, has identified many of the Tertiary fossils and assisted the writer in many other ways. The many helpful suggestions offered by Sidney Powers have been invaluable. The whole paper has been read and criticized by J. P. D. Hull.

EXPLOITATION

Long before the coming of the white man to northern Louisiana, the Indians came to Drake's, King's, Bistineau, and other salt domes for their supply of salt. Pottery débris, evidencing Indian occupation, is abundant on some of the salt domes, and the accounts of the earliest travelers in this region contain many references to the Indian trade in salt.

TABLE I

WELLS DRILLED ON THE INTERIOR SALT DOMES OF LOUISIANA

Company	Farm	Number	Location*	Year Completed	Total Depth (Feet)	Cap Rock (Feet)	Salt (Feet)
Arcadia:							
Arcadia Oil Co.	Anderson	1	29, 18 N., 5 W.	1920	2,257	No	No
Arcadia Syndicate	White	1	29, 18 N., 5 W.	1922	1,435	1,282	1,400
Arcadia Syndicate	Madden	1	19, 18 N., 5 W.	1922	2,000	1,412	1,443
Arcadia Syndicate	Pentecost	1	20, 18 N., 5 W.	1922	4,012	2,678	2,755
Arcadia Syndicate	McGuire	1	30, 18 N., 5 W.	1923	3,450	3,040	3,151
Arcadia Syndicate	Anderson	1	29, 18 N., 5 W.	1923	3,225	No	No
Vacherie:							
Standard Oil Co.	Jordan	1	16, 17 N., 8 W.	1922	897	709	799
Standard Oil Co.	Stephens	1	21, 17 N., 8 W.	1923	788	658	777
Standard Oil Co.	Scott	1	21, 17 N., 8. W.	1923	2,558	No	No
Standard Oil Co.	Woodard and Walker	1	16, 17 N., 8 W.	1924	1,872	No	No
Bistineau:							
Gulf Refining Co.	Bistineau	1	2, 17 N., 10 W.	1910	2,523	No	No
Gulf Refining Co.	Bistineau	2	35, 18 N., 10 W.	1913	2,305	1,375	1,500
American National Oil Co.	Crichton	1	26, 18 N., 10 W.	1920	3,245	No	No
King's:							
The Pardee Co.	Fee	1	35, 15 N., 8 W.	1914	404	161	175
The Pardee Co.	Fee	2	26, 15 N., 8 W.	1915	....	....	No
The Pardee Co.	Fee	3	26, 15 N., 8 W.	1915	1,442	1,413	No
Louisiana Oil Refining Corp.	Huckaby	1	27, 15 N., 8 W.	1921	2,232	?	No
Louisiana Oil Refining Corp.	Huckaby	2	27, 15 N., 8 W.	1921	2,505	No	2,228
Rayburn's:							
Hodge-Hunt Lbr.	Fee	2	29, 15 N., 5 W.	1923	3,003	No	No
Hodge-Hunt Lbr.	Fee	3	30, 15 N., 5 W.	1923	277	65	115
Price's:							
Vivian Oil Co.	Bodcau	1	25 13 N., 4 W.	†	†	†	†
Drake's:							
Savage Bros.	Artesian well	......	21, 12 N., 5 W.	1864–65	1,011	?	No
Savage Bros.	Fee	1	21, 12 N., 5 W.	1906	2,262	290	900
Savage Bros.	Fee	2	21, 12 N., 5 W.	1907	1,510	?	No
Winnfield Quarry:							
Tampico Oil Co.	So. Min. Co.	1	19, 11 N., 3 W.	1914	2,112	?	No
Cody Petroleum Co	So. Min. Co.	1	19, 11 N., 3 W.	1922	1,100	Surf.	999
Cody Petroleum Co.	So. Min. Co.	2	24, 11 N., 4 W.	1922	1,242	No	No
Gulf Refining Co.	So. Min. Co.	1	30, 11 N., 3 W.	1923	4,021	?	No
Coochie Brake:							
Cody Petroleum Co	Edenborn	1	31, 10 N., 4 W.	....	1,912	No	No
Cody Petroleum Co	Edenborn	2	31, 10 N., 4 W.	....	3,000	No	No
Cedar Creek:							
The Pardee Co	Fee	1	31, 11 N., 2 W.	1914	1,120	806	No
The Pardee Co.	Fee	2	31, 11 N., 2 W.	1914	2,650	No	No
The Pardee Co	Fee	3	31, 11 N., 2 W.	1917	800	Yes	No
Pace *et al*	Pace	1	31, 11 N., 2 W.	1903–7	220 to 1,000	No	No
Pace *et al*	Pace	2	31, 11 N., 2 W.	1903–7		Yes	No
Winnfield Oil Co.	Butler	......	31, 11 N., 2 W.	1903–7		Yes	No
Winnfield Oil Co.	Clifford	......	31, 11 N., 2 W.	1903–7		?	No

* Section, Township, and Range, in this and following Tables.

† No record available.

The early settlers made salt for local consumption, but it was not until the time of the Civil War, when the federal blockade of the southern ports became effective, that salt-making commenced on a large scale. People then came from Texas, Arkansas, Mississippi, and even more distant states to engage in salt-making. Bistineau, King's, Rayburn's, and Drake's salt domes were the largest producers, but salt was made in considerable qualities, also, at several other localities during this period. Accurate records of the production are not available, but it is estimated that in 1862, 1863, and 1864 there were 1,000 to 1,500 people engaged in salt-making at Bistineau. The daily production from Rayburn's for the same period is estimated to have been 1,000 to 1,200 bushels. Production records and estimates are not available from the other domes, but it is known that King's, Drake's, and Price's domes were large producers of salt, and this fact is borne out by the number of brine wells and remnants of evaporating equipment found at these places. With the close of the war the making of salt on a large scale ceased.

Limestone was quarried at Winnfield before the Civil War and burned for lime, and at the present time a crushing plant with a daily capacity of more than 1,000 tons is in operation.

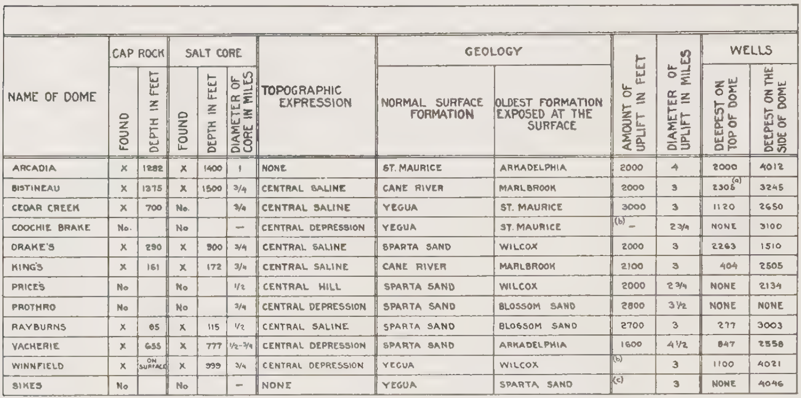
Exploration for oil and gas began in 1903, shortly after the discovery of oil at Spindletop, when the Winnfield Oil Company commenced the drilling of a well in Sec. 30, T. 11 N., R. 2 W., on Cedar Creek dome. This well penetrated cap rock at a depth of about 800 feet, and continued to a depth of about 900 feet, where, because of the hard rock and inadequate drilling equipment, it was abandoned.

The first deep well, reaching a depth of 2,523 feet, was drilled in 1910 by the Gulf Refining Company. It was located in Sec. 2, T. 17 N., R. 10 W., on the south flank of Bistineau dome. In all, more than 30 wells, all failures, have been drilled on or around the salt domes for the purpose of testing their oil and gas possibilities. A few of these have had small shows of oil; some gas; but none of sufficient volume to be considered a commercial well. Arcadia dome, with seven wells, and Vacherie dome, with four wells, have received the most thorough tests. Here are listed the wells drilled on and around the different domes (Table I).

GENERAL GEOLOGY

REGIONAL PHYSIOGRAPHY

The interior salt domes lie in that physiographic province of the Coastal Plain known as the hill lands of Louisiana. It is a dissected plain which slopes gently gulfward. It has an altitude of 350 to 400 feet above sea-level in the northern part, and 250 feet in the southern part of the salt-dome area. The region is drained by southward-flowing streams which empty into Red River to the west and south. From west to east these streams are Bayou Dorcheat, Black Lake Bayou, Saline Bayou, and Dugdemona Bayou. They flow in wide flat valleys, characteristic of the streams in northern Louisiana.



NAME OF DOME	CAP ROCK		SALT CORE			TOPOGRAPHIC EXPRESSION	GEOLOGY		AMOUNT OF UPLIFT IN FEET	DIAMETER OF UPLIFT IN MILES	WELLS	
	FOUND	DEPTH IN FEET	FOUND	DEPTH IN FEET	DIAMETER OF CORE IN MILES		NORMAL SURFACE FORMATION	OLDEST FORMATION EXPOSED AT THE SURFACE			DEEPEST ON TOP OF DOME	DEEPEST ON THE SIDE OF DOME
ARCADIA	X	1282	X	1400	1	NONE	ST. MAURICE	ARKADELPHIA	2000	4	2000	4012
BISTINEAU	X	1375	X	1500	3/4	CENTRAL SALINE	CANE RIVER	MARLBROOK	2000	3	2305(a)	3245
CEDAR CREEK	X	700	No.		3/4	CENTRAL SALINE	YEGUA	ST. MAURICE	3000	3	1120	2650
COOCHIE BRAKE	No.		No		—	CENTRAL DEPRESSION	YEGUA	ST. MAURICE	(b) –	2 3/4	NONE	3100
DRAKE'S	X	290	X	300	3/4	CENTRAL SALINE	SPARTA SAND	WILCOX	2000	3	2263	1510
KING'S	X	161	X	172	3/4	CENTRAL SALINE	CANE RIVER	MARLBROOK	2100	3	404	2505
PRICE'S	No		No		1/2	CENTRAL HILL	SPARTA SAND	WILCOX	2000	2 3/4	NONE	2134
PROTHRO	No		No		3/4	CENTRAL DEPRESSION	SPARTA SAND	BLOSSOM SAND	2800	3 1/2	NONE	NONE
RAYBURNS	X	65	X	115	1/2	CENTRAL SALINE	SPARTA SAND	BLOSSOM SAND	2700	3	277	3003
VACHERIE	X	655	X	777	1/2-3/4	CENTRAL DEPRESSION	SPARTA SAND	ARKADELPHIA	1600	4 1/2	847	2558
WINNFIELD	X	ON SURFACE	X	399	3/4	CENTRAL DEPRESSION	YEGUA	WILCOX	(b)	3	1100	4021
SIKES	No		No		—	NONE	YEGUA	SPARTA SAND	(c)	3	NONE	4046

(a) A short distance down the flank (b) Uplift greater than indicated in outcrops. (c) Uplift not determined but amounts to several hundred feet.

FIG. 4.—Table giving the essential characteristics of the interior salt domes of Louisiana.

SURFACE MANIFESTATIONS OF SALT DOMES

The surface manifestations of the salt domes of this region are the result of truncation of highly localized structures of great relief. Truncation, assisted in some places where the salt mass lies near the surface by the removal of salt in solution, has produced the peculiar topographic forms consisting of a central basin area encircled by hills. This form, which is the most common in the region, is well illustrated by Rayburn's and Prothro salt domes (Figs. 15 and 11). Another topographic form, not uncommon in Texas but represented in this region only by Price's salt dome (Fig. 17), consists of a central hill surrounded by a circular drainage system. Where truncation is deep and the salt mass near the surface, salt licks, or salines, barren or sparsely covered with vegetation, are usually grouped around the periphery of the central basin. Characteristic salt-dome features are steeply tilted rocks, outcrops of formations older than those usually found in the region, and springs of water, either fresh, slightly brackish, or mineralized with sulphur or alum.

STRATIGRAPHY

The Claiborne group of the Eocene is found at the surface in the salt-dome region of northern Louisiana, but older Eocene beds, as well as strata of Cretaceous age, appear at the surface in isolated outcrops on the domes. The oldest beds penetrated in the deep wells on and around the salt domes belong to the Comanchean series of the Cretaceous.

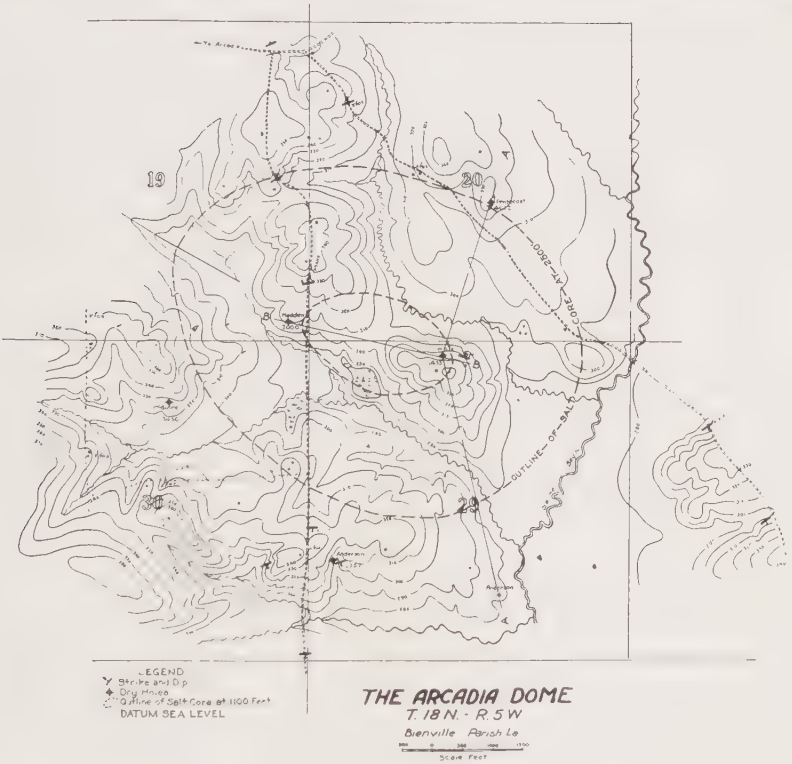


FIG. 5.—Topographic map of Arcadia salt dome

The brief discussion of the stratigraphy that follows is based largely on information obtained from the deep wells. The character and thickness of the several lithologic units can be determined with

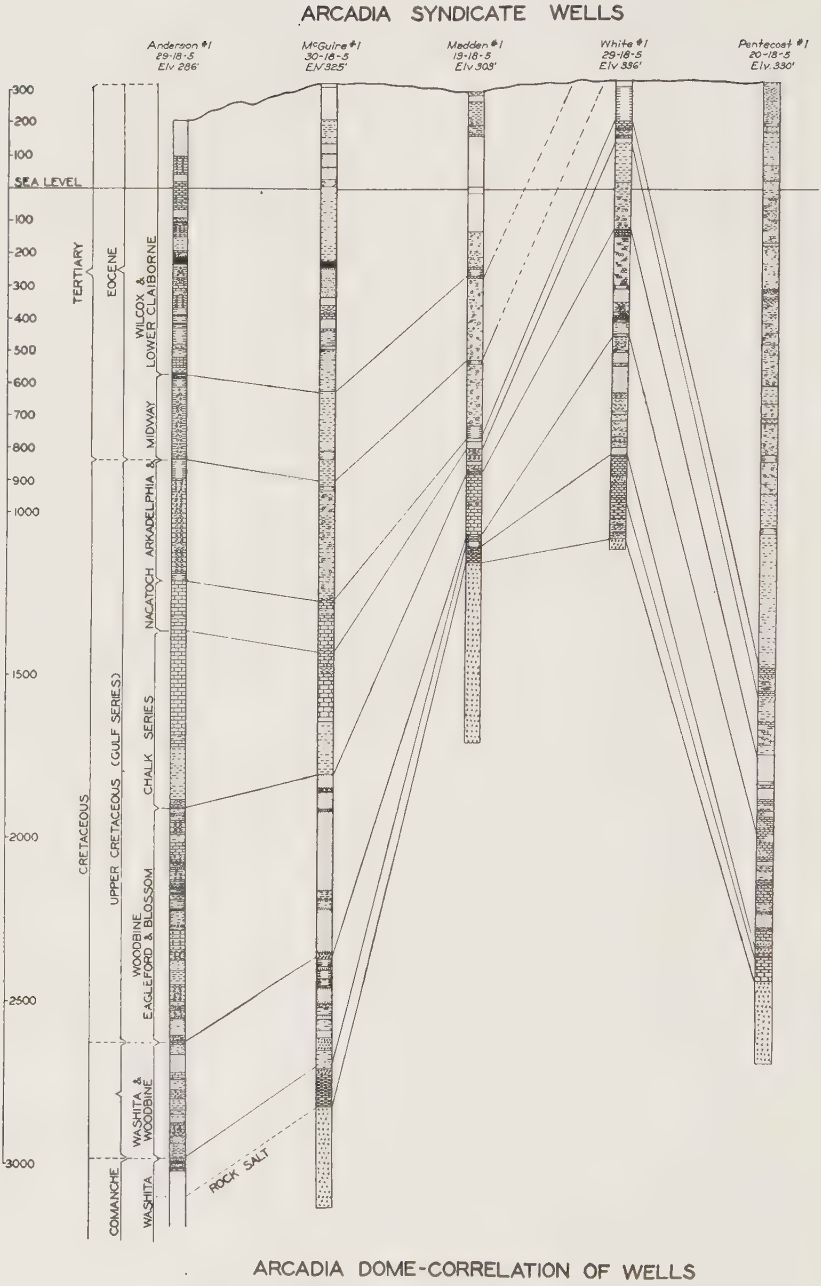


FIG. 6.—Well section on Arcadia salt dome

considerable accuracy, but correlation with the standard section of Texas is as yet a mooted question, and strongly emphasizes the need of systematic stratigraphic work, not only on material available from this region, but also in southern Arkansas, where these beds crop out.

A detailed discussion of the stratigraphy of each dome is given under the description of the salt domes.

The generalized stratigraphic section of this region is here given.

GENERALIZED SECTION OF FORMATIONS IN THE SALT-DOME REGION OF NORTHERN LOUISIANA

System	Series	Group	Formation	Thickness (Feet)
Quaternary	Recent			
	Pleistocene			
Tertiary	Eocene	Claiborne	Yegua	200–400
			St. Maurice	100–150
			Sparta sand	400–550
			Cane River	75–150
			Wilcox	800–2,500
			Midway	450±
Cretaceous	Gulf (Upper Cretaceous)		Arkadelphia	150–200
			Nacatoch	150–200
			Marlbrook Annona chalk Brownstown	550–650
		Bingen	Undifferentiated (Blossom sand at the top)	800–1,000
	Comanchean (Lower Cretaceous)	Washita Fredericksburg Trinity	Undifferentiated	3,000+

GULF SERIES (UPPER CRETACEOUS)

Following an erosion interval of some duration, Upper Cretaceous sedimentation began with a basal sand (Woodbine). The alternation of sand, shale, and chalk indicates many changes in the relative depth of the sea wherein these sediments were deposited, but no distinct unconformities within the series are recognizable. The lateral variation in the character and thickness of the basal beds (Bingen group) suggests that the sea advanced from the south and west, and that the sediments were derived from the Appalachian rather than from the Ozark mountain system.

The work of revising the stratigraphy of east Texas and south Arkansas is now under way; until this work is completed and correlated with the Louisiana sections, only a tentative correlation can be made for this region. The Gulf series is divided as follows:

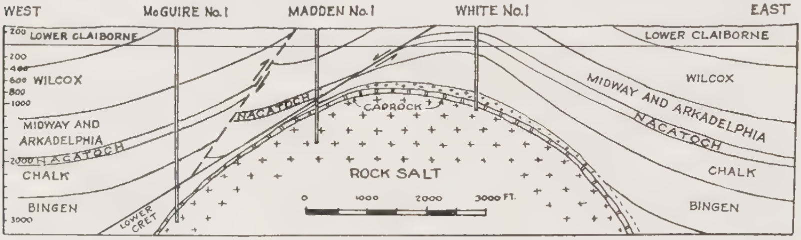


FIG. 7.—Cross-section of Arcadia salt dome

GENERALIZED SECTION OF UPPER CRETACEOUS FORMATIONS IN THE SALT DOME REGION OF NORTHERN LOUISIANA

Gulf Series (Upper Cretaceous)		Feet
Arkadelphia formation		150– 200
Nacatoch formation		150– 200
Marlbrook formation	Marl and chalk series	550– 650
Anona chalk		
Brownstown formation		
Bingen group (including Blossom sand at the top)		800–1,000

BINGEN GROUP

The Bingen group is herein used to designate those formations which, in the earlier publications, were correlated with the Blossom sand, Eagle Ford shale, and Woodbine sand. The name Bingen was applied to the basal Upper Cretaceous beds in southwestern Arkansas by Veatch[1] who considered them the equivalent of the Woodbine sand and Eagle Ford shale of Texas. Later stratigraphic work has proved that in part, at least, the beds formerly correlated with the Eagle Ford are younger in age, but until further stratigraphic work is done, it is not possible to differentiate the beds herein grouped in the Bingen.

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[1] A. C. Veatch, "Underground Water Resources of Northern Louisiana and Southern Arkansas," *U. S. Geol. Survey Prof. Paper 46*, 1906.

The Bingen group in the salt-dome region is in a general way divisible into these members: (1) sand 75–100 feet thick (Blossom sand), (2) marine shales in western part, sandy shale in eastern part, and (3) basal sand and clay.

The basal members usually begin with a red-clay member 10–40 feet, but locally as much as 100 feet, in thickness. Above this bed are 75–150 feet of alternating beds of sand, shale, and sandy shale in which plant remains and thin lignite partings are common. Chloritic material is present locally and accounts for the greenish and purplish tints of some of the sands in this member of the Bingen group.

The succeeding 600–700 feet of beds consist of marine shale and sandy shale. The shale predominates in the western part, and sandy shale in the eastern part, of the salt-dome region. None of the deep wells has penetrated these beds in the southern part of the area. The shales are gray to dark colored, and are in part chalky and calcareous. On the west side a thin limestone bed near the base is present in some places. Northeastward from this region these beds thin rapidly and are represented by sands which cannot be distinguished from the sands above and below.

The upper member of the group consists of 75–200 feet of sand, commonly known as the Blossom sand. It underlies all of this region but is known to outcrop at Rayburn's salt dome in Sec. 31, T. 15 N., R. 3 W., and at Prothro salt dome in Sec. 18, T. 14 N., R. 6 W. It is particularly well exposed in the latter locality. Where it outcrops in Louisiana it is a greenish-gray calcareous sandstone and, according to Ross,[1] who examined several samples from the outcrops and drill cores, it is made up of rounded quartz and novaculite, angular feldspar, and grains of igneous rock. It represents a horizon of volcanic tuffs that have been mixed with detrital material. The upper few feet of the sand is consistently coarse, often containing pebbles $\frac{1}{4}$–$\frac{3}{4}$ inch in diameter. The following well record illustrates the character of the Bingen group in the north-central part of the salt-dome region.

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[1] Clarence S. Ross, personal communication, July 22, 1924.

SECTION OF BINGEN IN ROXANA PETROLEUM CORPORATION—BRYAN NO. 1

Sec. 30, T. 17 N., R. 6 W.	Thickness (Feet)	Depth (Feet)
Blossom Sand:		
Sand	5	2,776
Sand, salt water	4	2,780
Hard sand	1	2,781
Fine soft sand with shale streaks	10	2,791
Sand	155	2,946
Sand and bowlders	2	2,948
Gumbo	8	2,956
Hard shale	20	2,976
Shale and bowlders	24	3,000
Sticky shale	5	3,005
Bowlders	10	3,015
Gumbo	3	3,018
Hard limestone	10	3,028
Broken lime and shale	14	3,042
Sandy shale	13	3,055
Sand and bowlders	30	3,085
Tough gumbo	9	3,094
Sand and bowlders	14	3,108
Hard limestone	9	3,117
Broken limestone and shale	10	3,127
Shale and gumbo, blue and gray	73	3,200
Broken limestone	20	3,220
Shale	67	3,287
Hard sand and gravel	13	3,300
Sandy shale, fossiliferous	53	3,353
Hard shale	37	3,390
Sandy shale	10	3,400
Sand	15	3,415
Shale and gumbo	24	3,439
Sandy shale	2	3,441
Hard shale	28	3,469
Sandy shale	3	3,472
Hard dark shale	53	3,525
Shale, sand streaks	38	3,563
Shale and gumbo	29	3,592

Sec. 30, T. 17 N., R. 6 W.	Thickness (Feet)	Depth (Feet)
Hard sand	1	3,593
Shale	23	3,616
Sand	24	3,640
Gumbo	11	3,651
Sand	18	3,669
Hard shale, sand streaks	51	3,720

CHALK AND MARL SERIES

Above the Bingen is a series of marl and chalk beds aggregating 550–600 feet in thickness. In the order of their deposition, these beds have been named the Brownstown marl, Annona chalk, and Marlbrook marl. The last-named formation includes the Saratoga-chalk member. The age relationship between these beds and the chalk beds of northeast Texas has not been determined. The beds are not normally at the surface in northern Louisiana, but isolated outcrops are found on several of the salt domes and are particularly well exposed on Rayburn's and Prothro salt domes in Bienville Parish.

The lower 150–200 feet of these beds consist of yellowish-green clay-marl with some interbedded, impure chalk. The upper 20–50 feet are gray sand and sandy clay. The succeeding 75–100 feet are hard, white chalk, and the upper portion of this series consists of shale, marl, and chalk. The amount of chalk is variable, but is most abundant in the southern and western parts of the salt-dome region. The following is a typical well record of this series:

SECTION OF CHALK SERIES IN ROXANA PETROLEUM CORPORATION—BRYAN NO. 1

Sec. 30, T. 17 N., R. 6 W.	Thickness (Feet)	Depth (Feet)
Chalky shale	30	2,190
Sticky shale	7	2,197
Chalky shale	21	2,218
Gumbo	10	2,228
Chalky shale	4	2,232
Limestone (hard chalk)	81	2,313
Chalk	101	2,414
Chalky shale	21	2,435
Chalk and sand	2	2,437
Broken limestone	4	2,441

Sec. 30, T. 17 N., R. 6 W.	Thickness (Feet)	Depth (Feet)
Chalky shale	35	2,476
Chalk	5	2,481
Chalk and limestone	59	2,540
Shale and gumbo	78	2,618
Sandy shale	9	2,627
Shale and gumbo	44	2,771

NACATOCH FORMATION

The Nacatoch formation is not known to crop out in Louisiana, although on some of the salt domes it occurs at very shallow depths below the surface. In the well logs it appears as limestone with interbedded thin sandstone members. In the southern part of the salt-dome region only closely cemented fine sand is present. The average thickness of the Nacatoch is about 200 feet.

ARKADELPHIA FORMATION

The uppermost Cretaceous of this region consists of 150–200 feet of dark-colored clays and chalky shales. In this formation were formerly included 300–400 feet of clays belonging to the Midway formation.

EOCENE

The Eocene sediments of this region comprise several hundred feet of sand, clay, marl, and lignite. These sediments were deposited under varying conditions, according as the strand line migrated back and forth over this region. The Eocene has been divided as follows:

GENERALIZED SECTION OF EOCENE FORMATIONS OF NORTHERN LOUISIANA

	Feet
Claiborne group:	
Yegua formation	200– 400
St. Maurice beds	100– 150
Sparta sand	400– 550
Cane River beds	75– 150
Wilcox formation	800–2,500
Midway formation	400+

MIDWAY FORMATION

The Midway formation underlies all of northern Louisiana, but does not appear at the surface unless it is on some of the salt domes, where lithologically similar beds are tentatively correlated with it.

The Midway consists of gray and dark-colored clay shale, containing an abundance of siderite concretions and, in some places, a slight amount of fine sand. On the outcrop in southern Arkansas, and in wells drilled in the Bellevue field in Louisiana, a fossiliferous limestone bed occurs at or near the base of the formation. This bed probably is present in other localities, but has not been recognized in the wells. The thickness of the Midway is about 400 feet, but it may be somewhat more in the southern part of the salt-dome region.

WILCOX FORMATION

The Wilcox formation, described in the earlier literature of this region as the Lignitic stage and as the Sabine formation, has been described by several writers, of whom Harris, Veatch, and Berry[1] are the important contributors.

The outcrop of the Wilcox formation in Louisiana extends from southern Sabine Parish to the Arkansas line, and from the Texas line to some miles east of Red River. It also crops out on some of the salt domes, notably on Prothro dome in Bienville Parish.

The Wilcox deposits of the salt-dome region consist of more or less extensive lenticular beds of sand and clay. The sands, which predominate, are commonly laminated, but also cross-bedded and massive in structure. Thin laminae-like partings of ferruginous sandstone, clay balls, and rounded sand concretions are commonly present. Calcareous sandstone and siderite concretions are abundant, and characteristic of this formation. The clays are usually finely laminated, and range in color from light buff to black. A considerable amount of lignitic matter is present in the Wilcox formation, either finely disseminated through the mass or accumulated in lignite beds. Mica in fine flakes is a common mineral in this formation.

The marine phase of the Wilcox outcropping in Louisiana is generally limited to Sabine Parish. The lowest marine beds occur in the latitude of Marthaville and Pendleton, and are correlated with the Nanafalia beds, lowermost Wilcox, in Alabama. Deep wells drilled in Sabine Parish in recent years have revealed the presence of not less than 2,500 feet of sands, and clays, in part lignitic and fossiliferous, which occupy the interval between the Nanafalia horizons and the Midway clays. According to George Stevens,[1] fossils from these beds were identified by the U. S. Geological Survey as Wilcox. From their stratigraphic position they are obviously older than the oldest Wilcox in the Alabama section.

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[1] G. D. Harris and A. C. Veatch, "A Preliminary Report on the Geology of Louisiana," *Geol. Survey of Louisiana, Report of 1899*, Part 5 (1900), pp. 64–73 and 299–309; "The Tertiary Geology of the Mississippi Embayment," *Geol. Survey of Louisiana, Report of 1902*, Part VI (1902), pp. 11–17; A. C. Veatch, "Underground Water Resources of Northern Louisiana and Southern Arkansas," *U. S. Geol. Survey Prof. Paper 46* (1906), pp. 34–36; E. W. Berry, "The Lower Eocene Flora of Southeastern North America," *U. S. Geol. Survey Prof. Paper 91*, 1916.

Marine Wilcox is not generally recognized in the wells which have been drilled in the salt-dome region, nor is any present on Prothro dome, where more than 800 feet of beds are exposed. Farther south, along the Angelina-Caldwell flexure where few wells have been drilled, the marine phase is probably as well developed as in Sabine Parish.

The Wilcox formation ranges in thickness from 800 feet in the northern part to more than 2,500 feet in the southern part of the dome region. The range in thickness is shown in a general way in Figure 3.

CLAIBORNE GROUP

The Claiborne group in Louisiana has been divided into an upper and a lower member. The upper member is represented by the Yegua formation, described in the earlier literature as the Upper Lignitic and the Cockfield formation. The lower member was designated as Lower Claiborne, or the Lower Claiborne stage, until 1920, when Harris[2] applied the name "St. Maurice formation" to the Lower Claiborne member. The name was taken from the type locality of St. Maurice, Natchitoches Parish, Louisiana. The St. Maurice formation, as defined by him, includes all of the beds above the Wilcox formation and below the Yegua formation.

The deep wells drilled in this region, many of which were carefully sampled and cored, have aided in giving a better understanding of the succession, character, and thickness of the Lower Claiborne beds than could be obtained from a study of the scattered outcrops.

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[1] Personal communication.

[2] G. D. Harris, "Lower Tertiary of Louisiana," *Science*, New Series, Vol. 31 (1910), p. 502.

The accumulated data suggest that they are divisible, on lithologic and paleontologic grounds, into three distinct members, either one of which may be ranked as a formation. For convenience in describing the geology of the region the following names have been used to designate these divisions—Lower Claiborne: St. Maurice beds, Sparta sand, Cane River beds.

CANE-RIVER BEDS

In the Cane River are included the 75–150 feet of beds above the Wilcox formation and below the massive Sparta sand. The name Cane River, from the excellent exposures on Cane River at Natchitoches, Louisiana, was suggested by H. V. Howe.

These beds outcrop in a narrow belt trending northeast across southern Sabine and Natchitoches parishes. A few miles east of Red River the strike changes to northwest, and continues in that direction to the Arkansas line. The width of the outcrop is 3–7 miles.

An erosional unconformity separates the Cane River and Wilcox beds. The basal member consists of glauconitic sand and sandy clay, but in some places marine tuff is present at the base. Glauconitic clays predominate in the southern portion of the outcrop, but northward from Bienville Parish they become sandier, until, in northern Bossier Parish, they are represented entirely by sands, in part glauconitic, and containing a meager representation of the prolific fauna found farther south. The fauna of the Cane River beds have been described by Harris[1] and Vaughan.[2] Harris groups the fauna under the St. Maurice and Claiborne stage, and Vaughan makes the following statement concerning these beds: "For Alabama, Mississippi, and Louisiana, excepting Natchitoches, the species are very nearly the same in all of these states for this division of the Claiborne. and apparently all belong to that horizon of the Lower Claiborne called the Lisbon beds." Vaughan[3] lists the following species typical of the Cane River beds from Natchitoches, Louisiana: *Amphihelia*

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[1] G. D. Harris, "Pelecypoda of the St. Maurice and Claiborne Stages," *American Paleontology*, Vol. 6 (1919), No. 31.

[2] T. W. Vaughan, "The Eocene and Lower Oligocene Coral Faunas of the United States," *U. S. Geol. Survey Monograph 39*, 1900.

[3] *Op. cit.*, p. 27.

natchitoensis Vaughan, *Madracis ganei* Vaughan, *Endopachys maclurii* (Lea), *Balanophyllia augustinensis* Vaughan.

From this statement it is obvious that Vaughan recognized a faunal province distinct from the remainder of the Lower Claiborne.

The Cane River beds, as shown in records of wells drilled east and southeast of the outcrop, are made up chiefly of glauconitic clays with subordinate beds of sand. The thickness increases slightly in the eastern and southeastern parts of the salt-dome region.

SPARTA SAND

This division of the Lower Claiborne is limited below by the Cane River beds and above by the lowest fossiliferous horizon of the St. Maurice beds. The name "Sparta sand" was used by Vaughan[1] in 1896 to designate certain sands and gravels which, from his description of their areal distribution, included the Sparta sand as defined above, as well as portions of the Catahoula sandstone of Oligocene age, and the Citronelle formation of Pliocene age.

The Sparta sand, owing to the steep dips along the Angelina-Caldwell flexure, outcrops in a narrow belt from Sabine River to the northern end of Saline Lake. From this point northward to the vicinity of Minden it has a width of 10–15 miles.

The lower half of the Sparta sand is made up chiefly of massive sand with interbedded subordinate members of laminated sandy clay. The massive sands are made up of quartz grains somewhat coarser than found in the Wilcox formation. The upper half contains a relatively greater amount of clay than the lower half. Massive sands alternate with beds of finely laminated sandy clay, in part lignitic and in many places containing fossil leaves. The upper 50 feet of beds contain a considerable amount of lignitic material and some thin lignitic beds which are particularly well exposed in the vicinity of the town of Bienville. The beds are commonly light colored, but, depending upon the amount of iron and carbonaceous matter, red- and brown-colored beds occur. Fossils are generally absent from the Sparta sand, but a few species of near-shore forms are found near the middle of the formation. The Sparta sand has a thickness of 400–500 feet, with the greater thickness in the northern part of the salt-dome region.

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[1] T. W. Vaughan, "A Brief Contribution to the Geology and Paleontology of Northwestern Louisiana," *U. S. Geol. Survey Bull. 142* (1896), p. 25.

ST. MAURICE BEDS

The St. Maurice includes the beds above the Sparta sand and below the Yegua formation, and is the equivalent of the upper part of the St. Maurice formation as defined by Harris.[1]

The St. Maurice beds, like the Cane River and Sparta sand, outcrop in a narrow belt across Sabine, Natchitoches, and Winn parishes. The outcrop gradually increases in width from Winnfield northward to Ruston on the Vicksburg, Shreveport & Pacific Railroad. The area north of the railroad, to the vicinity of the Arkansas line and eastward to the Ouachita River valley, is chiefly St. Maurice, although many remnants of the Yegua formation are present. This portion of northern Louisiana has not been mapped in enough detail to show the distribution of the St. Maurice and the Yegua formations.

The St. Maurice is made up of alternating beds of sands and clays. The sands predominate; they commonly range in color from light gray to red, but in some places are brown, owing to the carbonaceous matter they contain. In structure they are massive, cross-bedded, and laminated. They contain considerably more ferruginous sandstone than is present in the underlying Sparta sands. The clays are gray, green, red, and brown in color, depending upon the iron, glauconite, or carbonaceous content of the individual beds. The glauconitic beds are usually massive, but the sandier clays and the lignitic clays are often laminated. The basal and the upper beds are fossiliferous, and at least one other fossiliferous horizon occurs between the two horizons mentioned. The more perfect fossil shells and corals are found in the glauconitic clays and sands, but an abundance of fossil casts occur in the ferruginous concretions and in the thin ferruginous sandstone beds. The thickness of the St. Maurice beds ranges from 100 to 150 feet.

YEGUA FORMATION

The upper Claiborne is represented in this region by the Yegua formation, which, in the early Louisiana literature, was designated as Upper Lignitic and Upper Claiborne. Vaughan,[2] in 1896, applied the name "Cocksfield Ferry beds," and Veatch,[1] in 1905, used the name "Cockfield formation." The equivalent beds in Texas were named the Yegua formation by Dumble[2] in 1892. As the latter name had priority it was adopted by the U. S. Geological Survey Committee as the geologic name.

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[1] G. D. Harris, "The St. Maurice and Claiborne Stages," *American Paleontology,* Vol. 6 (1919), No. 31.

[2] T. W. Vaughan, "A Brief Contribution of the Geology and Paleontology of Northwestern Louisiana," *U. S. Geol. Survey Bull. 142* (1896), pp. 21–22.

The Yegua formation outcrops in a narrow belt across southern Sabine Parish. Beginning in the southeast corner of Winn Parish, the outcrop gradually increases in width to the east and north. In the vicinity of Winnfield the strike changes to north, and these beds are exposed in a wide belt as far as the Vicksburg, Shreveport & Pacific Railroad. Their eastern extension is limited by the Ouachita River valley.

The Yegua formation is predominantly sandy; massive, light-colored sands alternate with laminated and thin-bedded sandy clays and lignitic clay. The beds are generally light colored, but often red and brown. The maximum thickness of the Cockfield does not exceed 500 feet. Fossil leaves are present in the lignitic clays in many places, but marine fossils are not found in this formation.

VACHERIE SALT DOME

LOCATION AND HISTORY

Vacherie salt dome is located about 4 miles east of the town of Heflin. The center of the uplift lies on both sides of Webster-Bienville Parish line, in Secs. 16 and 21, T. 17 N., R. 8 W. It is 10 miles southeast of Bistineau, and 16 miles southwest of Arcadia salt dome.

Discovery of this dome was made as the result of field work by S. C. Stathers, chief geologist of the Standard Oil Company of Louisiana, who mapped this area in 1921. The writer is indebted to Mr. Stathers and his department for most of the data concerning the wells drilled on this dome. Vacherie was proved to be a salt dome in August, 1922, when the Standard Oil Company of Louisiana, drilling in Sec. 16, T. 17 N., R. 8 W., Webster Parish, struck rock salt at 799 feet. The second well was drilled just across the line in Section 21, Bienville Parish, where the salt was found at a depth of 777 feet.

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[1] A. C. Veatch, "A Report on the Underground Waters of Louisiana," *Geol. Survey of Louisiana, Report of 1905, Bull. No. 1* (1905), pp. 31–32.

[2] E. T. Dumble, "Report on Brown Coal," *Geol. Surv. of Texas* (1892), pp. 148–54.

Two more wells were drilled, one on the north and the other on the south flank of the dome. They were abandoned in the Lower Cretaceous and did not reach the salt mass.

TOPOGRAPHY

Vacherie dome (Fig. 8) is in an area of rugged hill lands, characteristic of the outcrops of the Sparta sand, in the northern part of the salt-dome region. The center of the dome is represented by a basin across which Vacherie Creek flows eastward in a broad, flat valley, and from which it passes through a narrow steep-sided valley in the high encircling hills. The sides of this basin slope gently upward to the base of the high encircling hills, which rise 150 feet above the valley of Vacherie Creek. The center of the low area is underlain by Midway and Arkadelphia clays; the surrounding parts, by Wilcox sands and clays. Radial streams rising on the flanks of the high hills flow into Vacherie Creek from all directions. Fresh-water springs are numerous around the base of the hills, and a spring of sulphur water is present in the SW. ¼ of Sec. 15, T. 17 N., R. 8 W. This spring, according to people living in the vicinity, has increased several times in volume during the past fifteen years.

TABLE II

WELLS DRILLED ON VACHERIE SALT DOME

Company	Farm	Number	Location	Year	Total Depth (Feet)	Cap Rock (Feet)	Salt (Feet)
Standard Oil Co.	Jordan	1	16, 17 N., 8 W.	1922	897	709	799
Standard Oil Co.	Stephens	1	21, 17 N., 8 W.	1923	788	658	777
Standard Oil Co.	Scott	1	21, 17 N., 8 W.	1923	2,558	No	No
Standard Oil Co.	Woodard and Walker	1	16, 17 N., 8 W.	1924	1,872	No	No

SURFACE GEOLOGY

The Sparta sand outcrops in the high encircling hills. The Cane River beds are generally concealed by the inwash of sand from the overlying Sparta beds, but a good outcrop occurs in the side of the road near the SE. cor. of SW. ¼ of SW. ¼, Sec. 9, T. 17 N., R. 8 W. It consists of fossiliferous, glauconitic, green clay. The dips are 18 degrees NE. Another outcrop of Cane River beds is near the NW.

cor. of SE. ¼, Sec. 15, T. 17 N., R. 8 W. This bed is less calcareous than the first described, but consists of typical glauconitic clay. The Wilcox formation is exposed in several places, but where the Cane River beds are concealed, it is not easily distinguished from the Sparta sand. It outcrops along the road in the NW. ¼, Sec. 16, T. 17 N., R. 8 W., but is best exposed in the ditches along the road which parallels the W. line of Sec. 22, T. 17 N., R. 8 W. It is made up of massive, grayish-blue clays which are highly fractured. Ferruginous clay and ironstone concretions are abundant in these beds, and sometimes contain leaf impressions. Bedding planes are poorly developed and the dip is not determinable, but appears to be high. The Midway and Arkadelphia formations outcrop in extensive

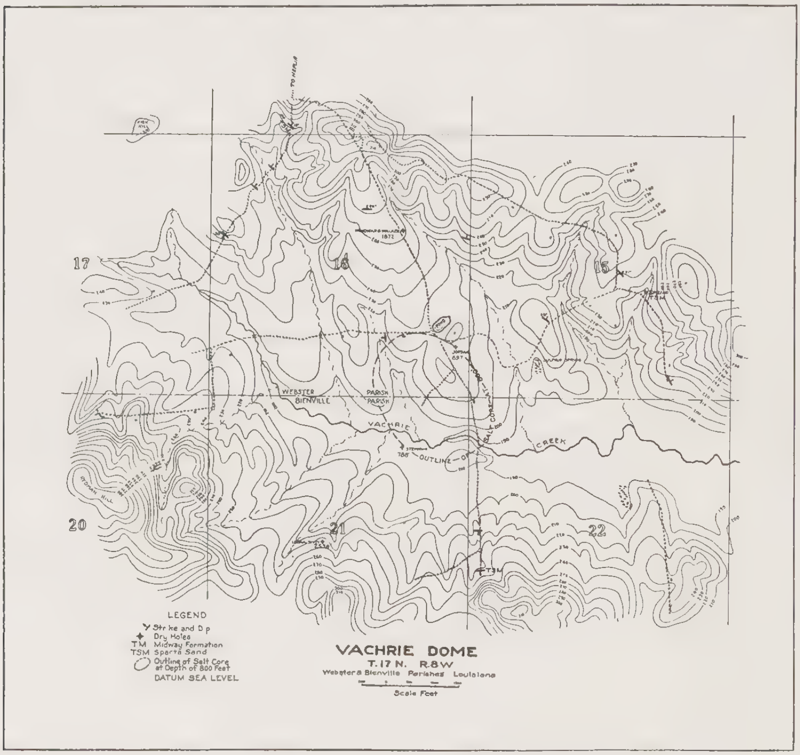

FIG. 8.—Topographic map of Vacherie salt dome showing characteristic central basin.

areas in the center of the dome. They are in most places covered with a veneer of sand and gravel. Because of their lithologic similarity and the faulting of these beds, their relative extent cannot be determined. The most important outcrops are shown in Figure 8.

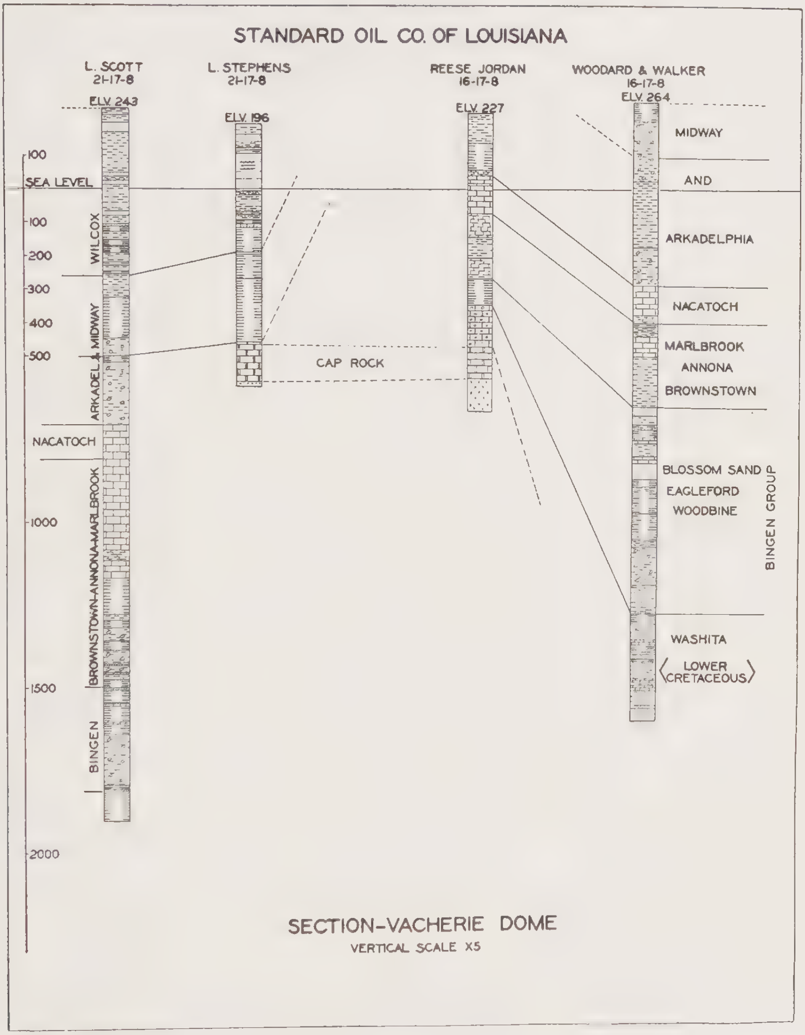

FIG. 9.—Well sections on Vacherie salt dome

UNDERGROUND GEOLOGY

Four wells were drilled on this dome by the Standard Oil Company of Louisiana. Reece Jordan No. 1, in Section 16, the first well drilled, started in the Arkadelphia formation and reached rock salt at a depth of 799 feet. L. Stephens No. 1, located in Section 21, started in the Wilcox formation and found rock salt at 777 feet. L. Scott No. 1, in Section 21, and Woodard & Walker No. 1, in Section 16, were abandoned in the Washita group of the Lower Cretaceous at depths of 2,558 feet and 1,872 feet, respectively. These wells were drilled under the supervision of Mr. Stathers, and no efforts were spared in securing complete records of the formations encountered. F. X. Bostick, the company's paleontologist, correlated the formations in these wells as follows (see Fig. 9):

GEOLOGIC SECTION OF REESE JORDAN NO. 1, SECTION 16

	Feet
Upper Cretaceous:	
Arkadelphia formation	0–188
Nacatoch formation	188–301
Chalk and marl	301–495
Bingen group	495–575
Lower Cretaceous:	
Washita group	575–709
Cap rock	709–799
Rock salt	799–897

GEOLOGIC SECTION OF L. STEPHENS NO. 1, SECTION 21

	Feet
Tertiary:	
Wilcox formation Midway formation	0–658
Cap rock	658–777
Rock salt	777–888

GEOLOGIC SECTION OF L. SCOTT NO. 1, SECTION 21

	Feet
Tertiary:	
Wilcox formation	0–556
Midway formation Upper Cretaceous: Arkadelphia formation	556– 953
Nacatoch formation	953–1,052
Chalk and marl	1,052–1,748
Bingen group	1,748–2,251
Lower Cretaceous:	
Washita group	2,251–2,558

GEOLOGIC SECTION OF WOODARD & WALKER NO. 1, SECTION 16

	Feet
Tertiary:	
Midway formation Upper Cretaceous: Arkadelphia formation	0– 550
Nacatoch formation	550– 675
Chalk and marl	675– 918
Bingen group	918–1,543
Lower Cretaceous:	
Washita group	1,543–1,872

CAP ROCK

The cap overlying the salt core is 90–120 feet thick in the wells drilled on the dome. It is white and light gray anhydrite with irregular dark gray and blue banding, quite similar in appearance to the calcite cap rock on the Winnfield and other salt domes.

LOWER CRETACEOUS

Washita group.—The oldest beds penetrated on this dome belong in the Washita group of the Lower Cretaceous. The most interesting, and perhaps the most significant, occurrence is found from 575 to 709 feet in the Jordan No. 1 well. It is a fossiliferous conglomerate made up of well-rounded red-, blue-, green-, and gray-colored limestone pebbles and smoky quartz and chert pebbles. The matrix is a fine-grained, angular quartz sand and green-colored argillaceous material. The mass is firmly cemented with calcite. The only recognizable fossil in this bed is *Ostrea navia* Hall, which is abundant in the Kiamitia clays, basal Washita of the Texas Lower Cretaceous section. This conglomerate is similar to that found in the same position relative to the cap rock on Arcadia salt dome.

The Washita beds found in Scott No. 1 well and Woodard & Walker No. 1 well are made up of shale, gumbo, sand, and limestone which, so far as can be determined from the inclosed fossils, probably are not older than the Weno clay, basal Upper Washita of the Texas section. The section penetrated in Scott No. 1 well is as follows:

DETAILED SECTION OF WASHITA BEDS IN SCOTT NO. 1, SECTION 21

	Depth (Feet)	Thickness (Feet)
Lower Cretaceous (Washita group):		
Gumbo	41	2,292
Shale	3	2,295
Sandy lime	5	2,300
Gumbo	18	2,318
Shale	13	2,331
Gumbo	9	2,340
Shale	20	2,360
Sand and limestone	2	2,362
Broken limestone	14	2,376
Broken lime and gumbo	27	2,403
Limestone and pyrite	29	2,432
Packed sand	26	2,458
Sandstone	14	2,472
Tough gumbo	19	2,491
Broken rock	2	2,493
Sandstone	10	2,503
Gumbo	39	2,542
Limestone	16	2,558

The Washita conglomerate present on Vacherie and Arcadia domes has not been recognized in the many deep wells which have penetrated this formation elsewhere in northern Louisiana.

UPPER CRETACEOUS FORMATIONS

The Upper Cretaceous section found in the wells drilled on this dome does not differ greatly in character from the normal section of the region. The wide difference in thickness of the beds is due chiefly to faulting, though stretching of the beds during folding may have affected the shale members in some slight degree.

STRUCTURE

The structure of Vacherie dome is typical of salt-dome structure of this region. The central salt core, slightly elongated northwest and southeast, is about 2,500 feet in diameter at a depth of 800 feet below the surface. The inclination of the salt surface is not known. The salt is surmounted by a cap of anhydrite 90 to 120 feet thick. The sedimentary beds involved in the uplift are arched and pierced by the intrusion of the salt. The total vertical relief of this dome is about 1,600 feet, and the area affected by the uplift is about 4 square miles. The structure of Vacherie dome is complicated by faulting, more than any other dome in this region of which we have equally complete records. A cross-section of Vacherie dome is shown in Figure 10, constructed from well records and surface outcrops. The well sections, areal distribution of the beds at the surface, and the dips of these beds harmonize, so far as the incomplete data show. The faulting is mainly peripheral, and probably represents segments of the arch, formed by the intrusion of the salt core, which failed under the continued pressure applied from beneath.

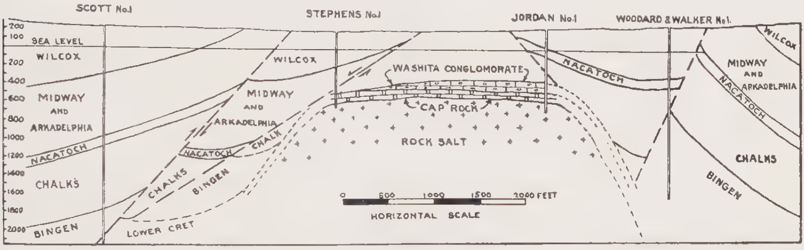

FIG. 10.—Cross-section of Vacherie salt dome showing faulting of sedimentary beds around the salt core.

PROTHRO SALT DOME

LOCATION AND HISTORY

Prothro salt dome is located 4 miles northwest of the town of Saline, in southern Bienville Parish. The center of the uplift is in Secs. 8 and 17, T. 14 N., R. 6 W. It is 8 miles southeast of King's and 5 miles southwest of Rayburn's salt domes.

This dome remained unknown until recently. In July, 1922, J. P. D. Hull, in company with J. L. Dormon, lawyer of Shreveport, Louisiana, visited this locality. Mr. Dormon was once a resident of Saline, where he had become familiar with the locality, and recognized the unusual character of the rock exposed. Mr. Hull mapped the essential geologic features of this dome, and the writer is indebted to him for much of the information here presented. In February, 1924, Mr. Hull accompanied Sidney Powers and the writer to this locality, and the name Prothro, from Prothro Mill Creek, located on the dome, was agreed upon. The dome has not yet been tested by drilling.

TOPOGRAPHY

Prothro dome (Fig. 11) consists of a central low, somewhat marshy, area one mile long and half a mile wide. The central area is encircled by an inner rim of low hills and an outer rim of higher hills on the north, west, and south sides. The central low area has an altitude of 190–200 feet above sea-level, and the inner rim of hills is 40–50 feet higher. The outer rim of hills merges with the rugged hill lands of this area. Their elevation is from 310 to 350 feet, giving a total relief of 150 feet.

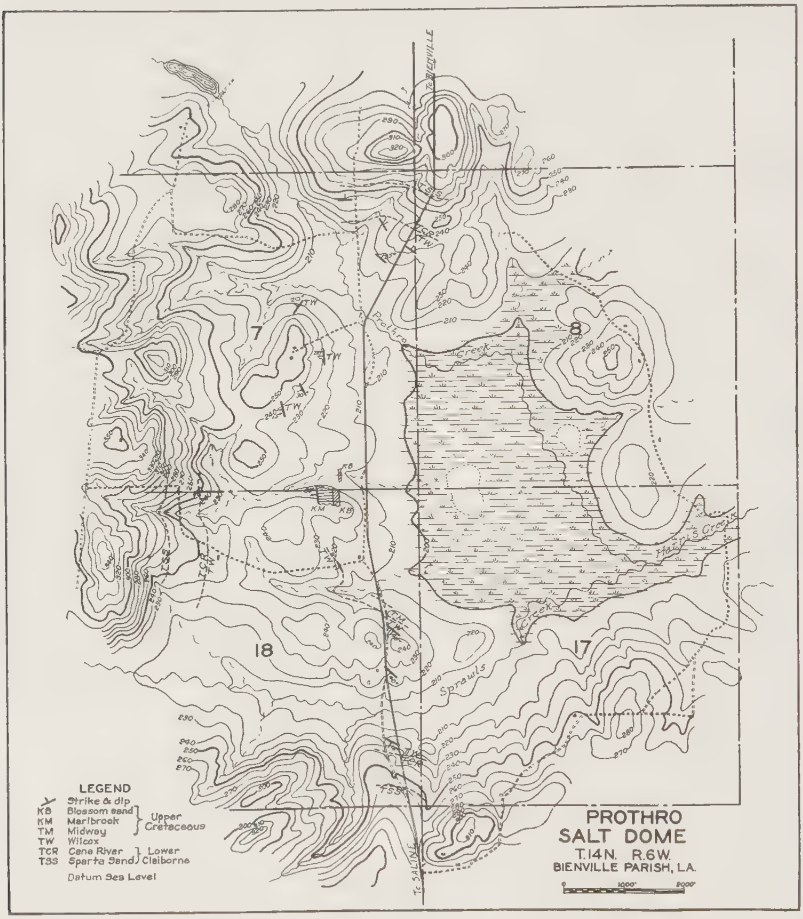

FIG. 11.—Topographic map of Prothro salt dome showing characteristic central basin and encircling rims of hills.

The central low area represents the highest part of the uplift, or that part of it underlain by the salt mass. Truncation of the dome by erosion and removal of salt by solution accounts for this marked basin. The Cretaceous and older Tertiary beds, including the Wilcox formation, are exposed in the low inner rim of hills. The high outer rim of hills is composed of Sparta sand, with Cane River beds at its base.

The salt-dome area is drained by Prothro and Sprawls creeks. Prothro Creek rises on the north side and enters the central basin on the northwest side. Sprawls Creek rises on the southwest side of the dome, flows eastward to enter the low area on the south side. Prothro and Sprawls creeks join near the east side of the dome to form Harris Creek, which empties into Saline Bayou about 2 miles farther east. Radial streams, fed by surface waters and springs, empty into the central basin from all directions.

SURFACE GEOLOGY

The geology of Prothro dome is of more than usual interest because of the fine section of Tertiary beds exposed there, which is not equaled in any locality in northern Louisiana. The Sparta sand, the normal formation at the surface in the locality, is exposed in the high hills encircling the dome. Cane River beds outcrop at the base of the high hills. The Wilcox formation and probably a part of the Midway formation crop out in the low inner rim of hills. Upper Cretaceous rocks more than 300 feet in thickness, including the Blossom sand at the base, crop out on the west side of the dome.

UPPER CRETACEOUS FORMATIONS

Beds of Upper Cretaceous age consisting of chalk, marl, and calcareous sandstone crop out in a small area in Secs. 7 and 18, T. 14 N., R. 6 W., where the following section was determined:

DETAILED SECTION OF UPPER CRETACEOUS ROCKS EXPOSED IN SECS. 7 AND 18, T. 14 N., R. 6 W.

	Feet
Upper Cretaceous:	
1. Fine-grained fossiliferous white chalk, thin bedded and fractured. Thin bed of sandy limestone at the base. Top concealed	160

	Feet
2. Somewhat chalky greenish-gray, fossiliferous clay. Weathers a reddish-brown	50
3. Fossiliferous, greenish-gray calcareous sandstone. Upper few feet contain many small pebbles	110

The sandstone at the base of this section is correlated with the upper part of the Bingen group, locally known as the Blossom sand. It is a greenish-gray calcareous sandstone, made up of rounded quartz grains and novaculite, angular feldspar, and grains of igneous rocks, which, according to Ross,[1] who examined several samples of this rock, represents a horizon of volcanic tuffs that have been mixed with detrital material. The upper few feet of this bed are decidedly coarse, containing many pebbles, $\frac{1}{8}$ to $\frac{1}{4}$ inch in diameter. The strike is N. 20 W., and the dip 90 degrees.

The following fossils from the bed have been identified by L. W. Stephenson: *Cassidulus* sp., *Cucullaea* sp., *Inoceramus* sp., *Ostrea plumosa* Morton, *Trigonia* sp., *Serpula*(?), *Pugnellus* sp., *Placenticeras* sp., *Cardium* sp., *Crassitellites*(?), young individual. *membranipora* and *Herteropora* have been identified by R. S. Bassler. The sandstone bed is overlain by about 50 feet of yellowish-green marly clay, containing some argillaceous chalk. It is followed by 160 feet of fine greenish-white chalk, highly fractured and containing many small marcasite concretions. Calcite crystals, considerable vein calcite, and barite are associated with the chalk. The basal 3 or 4 feet of the chalk are sandy. The beds strike N. 20 W., and dip 80–85 degrees SW.

The following fossils collected from these beds were identified by L. W. Stephenson: *Inoceromus* sp., *Gryphaea vesicularis* Lamarck, *Anomia argentaria* Morton, *Cardium* (*Criocardium*) sp., *Ostrea cf. O. congesta* Conrad, *Exogyra càncellata* Stephenson, *Pholadomya*(?), *Exogyra costata.*

The chalk in the section is definitely Marlbrook in age, according to Stephenson,[2] and is about the horizon of the Saratoga chalk. The underlying clays appear to be older, and are perhaps the equivalent of a portion of the Brownstown formation.

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[1] Clarence S. Ross, personal communication.

[2] L. W. Stephenson, personal communication.

TERTIARY FORMATION

The lower 100 feet of the beds above the Cretaceous have been tentatively assigned to the Midway formation. These beds are followed by about 1,000 feet of the Wilcox formation, which, in turn, is overlain by Cane River beds and Sparta sand of the Lower Claiborne group.

MIDWAY FORMATION

About 100 feet of bluish-gray clay exposed along the highway in the NE. ¼ of Sec. 18, T. 14 N., R. 6 W., are tentatively correlated with the Midway formation. The lower 50 feet are dark bluish-gray clay, containing a small amount of find sand. The succeeding 25 feet of beds consist of waxy yellowish clay, characterized by conchoidal fracture. The upper 25 feet are bluish-gray clay, with irregularly distributed patches of fine sand sparsely scattered through it. The beds strike N. 40 W., and dip 50 degrees NE.

WILCOX FORMATION

Isolated small outcrops of Wilcox beds are found in many places on the north and west sides of the dome, but the best and most complete section of these beds is along the highways in Sec. 18, T. 14 N., R. 6 W., where the following section is shown:

DETAILED SECTION OF WILCOX BEDS IN SEC. 18,
T. 14 N., R. 6 W.

	Thickness (Feet)
Wilcox formation:	
1. Bluish-green sandy clay with partings of ferruginous sand	200
2. Massive, cross-bedded, red sand with ferruginous concretions, thin lenses, and balls of light-colored clay	150
3. Yellow sandy clay with small fragments of limonite and thin partings of ferruginous sandstone	450
4. Yellow and gray clay, thinly laminated, with rounded sand concretions 1 to 2 inches in diameter	25
5. Gray, slightly sandy clay, laminated, leaf impressions	75
6. Light-colored and mottled sandy clay; limonite and siderite concretions abundant in the lower 50 feet	100

The basal bed is light-colored, massive sandy clay in part mottled red and white. Limonite and siderite concretions are scattered through the mass, but are most abundant toward the base. The concretions range in size from a few inches to more than 2 feet in diameter. This bed is about 100 feet thick; it strikes N. 36 W., and dips 45 degrees SW.

The succeeding 75 feet of beds are gray, laminated, slightly sandy clay. The laminae range from $\frac{1}{4}$ to 1 inch thick in the upper part and from 1 to 3 inches thick in the lower part, of the beds. Leaf impressions and rounded sand concretions $\frac{1}{2}$ to 1 inch in diameter are scattered through these beds. The strike is N. 35 W., and the dip is 45 degrees SW.

The next 25 feet consist of thinly laminated yellow and gray clay. Round, sand-filled ferruginous concretions, 1–2 inches in diameter, occur in the beds.

The succeeding 450 feet are made up of yellow and gray sandy clays and clayey sand. Small fragments of limonite and many thin partings of ferruginous sandstone are present in these beds. The strike is N. 35 W., and the dip is 40 degrees SW.

The last-described bed is overlain by about 150 feet of massive cross-bedded red- and orange-colored sand, with many irregular thin lenses of grayish-green and white clay flakes. Clay balls and irregular-shaped ferruginous concretions are scattered through the sands. The dip and strike are not determined.

The uppermost beds of the Wilcox formations consist of bluish-green sandy clay, interbedded with thin beds of ferruginous brown sand and sandstone. These beds are about 200 feet thick. The strike is N. 30 W., and the dip is from 6 to 16 degree SW.

CLAIBORNE GROUP

Cane River beds.—Cane River beds crop out on the north, west, and south sides, as shown in Figure 12, but they are perhaps best exposed along the highway on the south side of the dome, in the SE. cor. of Sec. 18, T. 14 N., R. 6 W., where they consist of 50–75 feet of massive glauconitic clay.

At the base this glauconitic clay weathers with a mottled effect of red and green. It is slightly sandy and contains many fragments of dark red chert thinly coated with chalcedony. The dip is undetermined, but the underlying Wilcox beds dip about 5 degrees SE.

It is followed by fossiliferous grayish-green marl. Near the base is a layer of gray concretionary limestone, which weathers to pale yellow on the outside. A layer of red-brown siderite, 1 to 2 feet thick, occurs at the top of this member. Above the siderite layer are a few feet of pale greenish, massive, sticky clay, with irregular dark red-brown streaks through it. It weathers to pale yellowish-brown.

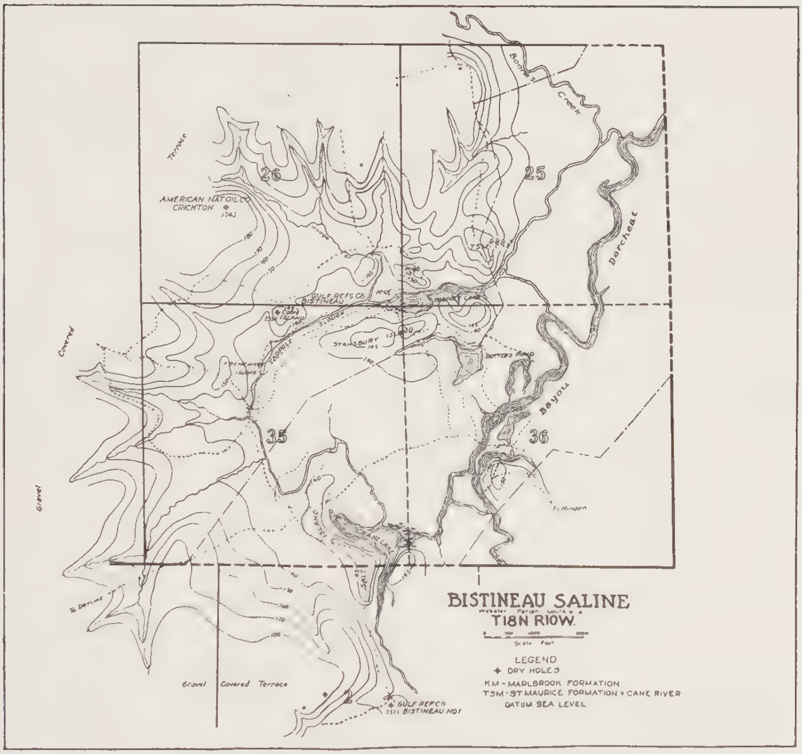

FIG. 12.—Topographic map of Bistineau salt dome

Because of the massive structure of these beds it is not possible to determine the dips accurately. The basal Cane River beds overlie Wilcox sands, dipping 5 degrees, and the dip apparently decreases rapidly southward.

Sparta sand.—The Sparta crops out in the high hills encircling the dome. It consists of massive red sands, with a few irregular lenses of light-colored clay. More than 100 feet of these beds are exposed around this dome.

STRUCTURE

The quaquaversal structure of Prothro dome is indicated in the dips of the rock outcropping on the north, west, and south sides. Although dips are lacking on the east side, there can be no reasonable doubt of their existence beneath the mantling of residual sand. The dome is deeply truncated by erosion. The central low area is perhaps in part due to the removal of salt by solution and a consequent lowering of the beds overlying it. The dip away from the central basin is steepest in the older rocks; the Blossom sand, the oldest formation exposed, stands vertical. The overlying chalk shows dips of 80 to 85 degrees. The Wilcox beds range from 50 degrees in the basal part to 5 degrees or less in the uppermost beds exposed. The strike of the different outcrops indicates a decided north-south elongation of this dome.

The vertical uplift determined on the Blossom sand outcrop is 2,800 feet, and the area affected by the uplift is slightly more than 3 miles in the direction of the longest dimensions of the dome.

BISTINEAU SALT DOME

LOCATION AND HISTORY

Bistineau salt dome is located in southern Webster Parish, about 4 miles south of the town of Doyline, on the Vicksburg, Shreveport & Pacific Railroad. The center of the uplift is in Sec. 35, T. 18 N., R. 10 W. It is 10 miles northwest of Vacherie salt dome and 12 miles southeast of the Bellevue oil field.

Evidences of Indian occupation are found on the south side of Potters Pond, which owes its name to the accumulations of pot débris about it. The Hodges brothers made some salt in 1850, but, except for a brief period in 1855 when drouth prevented boats from navigating the lake, it was not until the time of the Civil War that it was made in any considerable quantities. It is estimated that in the years 1862, 1863, and 1864 there were 1,000 to 1,500 people engaged in the making of salt at this locality. With the close of the war operation on a large scale ceased.

Bistineau salt dome was first described by Veatch[1] in his comprehensive report in 1902.

The salt wells drilled were shallow and, with one or two exceptions, did not exceed 20–25 feet in depth. The first well drilled for the purpose of testing the oil and gas possibilities of this dome was the Gulf Refining Company—Bistineau No. 1—in Sec. 2, T. 17 N., R. 10 W. Two more wells were drilled on the north flank of the dome, one of which reached rock salt.

TABLE III

WELLS DRILLED ON BISTINEAU SALT DOME

Company	Farm	Number	Location	Total Depth (Feet)	Year	Salt (Feet)
Gulf Refining Co.....	Bistineau	1	2, 17 N., 10 W.	2,523	1910	No
Gulf Refining Co.....	Bistineau	2	35, 18 N., 10 W.	2,305	1913	1,500
American National Oil Co...............	Crichton	1	26, 18 N., 10 W.	3,245	1920	No

TOPOGRAPHY

Bistineau salt dome (Fig. 12) lies beneath the bottom of the old raft lake[2] from which it derives its name. Since the removal of the raft, the levels of the lake have been lowered, and it is now represented in this area by Bayou Dorcheat.

The dome has a roughly circular central saline about one mile in diameter. On the east, where it merges into the bottom land along the bayou, it is distinguished by the barren, salt incrusted soil and the stunted growth of vegetation. The saline is in part barren and in part covered with a stunted growth of hawthorn, thick brush, and, here and there, a few cypress trees. Around the periphery of the saline is an almost continuous line of barren salt licks on which were located most of the old brine wells. Around the outer margin of the central saline are several low, wooded mounds that appear as islands when the saline and bottom lands are inundated. Many of these mounds were named by the early salt-makers.

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[1] A. C. Veatch, "The Salines of North Louisiana," *Geol. Survey of Louisiana, Report of 1902*, Special Paper No. 2 (1902), pp. 81–89.

[2] For description of the "raft lakes" of this period, see "Underground Water Supplies of Northern Louisiana and Southern Arkansas," *U. S. Geol. Survey Prof. Paper 46*, by A. C. Veatch.

A gentle slope of 40 feet, in a distance of about half a mile, separates the saline from the gravel-covered terrace surrounding the dome on all but the east side, where it merges with the wide bottom of Bayou Dorcheat.

The salt-dome region is drained by Bayou Dorcheat, flowing in a general southward direction along the east side of the dome. Radial streams, of which Hodges Branch, on the northwest side, is the largest, empty into the saline. The radial streams combine to form a circular drainage system that follows the outer margins of the saline. This drainage system is well defined during the periods in which the waters of Bayou Dorcheat are confined to its channels.

The central saline represents the highest part of the uplift and closely outlines the area wherein the salt core lies at a moderate depth below the surface.

SURFACE GEOLOGY

Bistineau salt dome lies in the area of an extensive terrace deposit, probably of Pliocene age. Cane River beds, the normal surface formation, appear in a small outcrop on the north side of the dome, and the Marlbrook formation crops out in Tadpole Lake. The terrace deposits of sand and gravel have concealed all other beds on and around the dome.

The Marlbrook is represented by a bed of yellow clay, or soft limestone, poorly exposed in the shallow waters of Tadpole Lake, in the SE. cor., Sec. 26, T. 18 N., R. 10 W. The strike and dip of this bed are not determinable. The formation contains a number of Upper Cretaceous fossils, of which the following have been identified: *Gryphaea vesicularis*, *Exogyra costata*, *Lima* sp., *Pecten quinquenarius*, *Pecten simplicus*, *Cucullaea* sp.

That Cane River beds underlie the gravel-covered terrace material on the outer edges of the dome is proved by fossils found in shallow-water wells, but they are known at the surface only in one locality, in the SW. ¼ of Sec. 25, T. 18 N., R. 10 W. They consist of glauconitic sand and clay, with limonite concretions containing a typical Cane River fauna. These beds dip to the north, but neither the strike nor the angle of inclination could be determined.

UNDERGROUND GEOLOGY

Little information is available concerning the underground geology of Bistineau salt dome, as no well has been drilled on top of the dome in recent years, and only one well on the flanks. According to Veatch,[1] a well drilled near the mouth of Hodges Branch during the Civil War was reported to have struck rock, at 125 feet, which could not be penetrated. Fragments of rock similar to the cap rock at Rayburn's and other domes are found in this locality, and the presumption is that the rock, at a depth of 125 feet, represents the cap rock. The Gulf Refining Company's Bistineau No. 2 well, in Sec. 35, T. 18 N., R. 10 W., located on the north flank of the salt core, but only a short distance from the maximum elevation of the core, had the following section:

SECTION OF GULF REFINING COMPANY'S BISTINEAU NO. 2

	Thickness (Feet)	Depth (Feet)
Surface sand	16	16
Midway and Arkadelphia formations	444	460
Nacatoch formation	88	548
Marlbrook formation Annona chalk Brownstown formation	550	1,098
Bingen group	211	1,309
Bingen or Washita	78	1,387
Cap rock	105	1,492
Hard shale(?), probably rock salt	370	1,862
Rock salt	443	2,305

The Crichton No. 1 well in Sec. 26, T. 18 N., R. 10 W., 2,300 feet northwest of the Bistineau No. 2 well, found the top of the Nacatoch formation about 1,000 feet lower, indicating a dip to the north of about 25 degrees.

STRUCTURE

The salt licks distributed along the outer margin of the central saline area will give an approximate measure of the areal extent of the top of the salt core and overlying cap rock. The inclination of the sides of the salt core is not known. The sedimentary strata around the salt core are sharply flexed and pierced. The amount of uplift measured on the outcrop of the Marlbrook formation is not less than 2,000 feet. The area affected by the uplift does not exceed 3 miles in diameter.

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[1] A. C. Veatch, "The Salines of North Louisiana," *Geol. Survey of Louisiana, Report of 1902*, Special Paper No. 2 (1902), p. 87.

KING'S SALT DOME

LOCATION AND HISTORY

King's salt dome is located in the southwestern part of Bienville Parish, about 8 miles northwest of Prothro salt dome and 14 miles south of Vacherie salt dome. The center of the uplift is in Sec. 25, T. 15 N., R. 8 W. The Louisiana & Arkansas Railway traverses the dome from north to south, and the town of Castor is situated on the north flank of the uplift.

Evidences of Indian occupation are present in arrowhead, stone implements, and pottery débris. Salt-making for local consumption by the white settlers was begun by a Mr. King in the early forties of the last century. According to Hilgard,[1] King dug a shallow well and, striking rock, drilled it to a depth of 136 feet. During the Civil War the production of salt was greatly increased at this locality, but no information is available regarding the daily production for this period. With the close of the war the production of salt on any considerable scale ceased.

It is of historic interest that the Cretaceous of Louisiana was first recognized in this locality. Robertson,[2] in 1867, reported fossiliferous Cretaceous limestone from King's salt works, but Hilgard[3] was first to bring forward proof of this occurrence by finding *Exogyra costata* in the dump heaps at Big Lick.

King's salt dome was described in detail by Veatch[4] in 1902.

The old wells drilled for brine were shallow and, with the exception of King's well, previously mentioned, seldom exceeded a depth of 30 feet.

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[1] E. W. Hilgard, *Supplementary and Final Report of a Geological Reconnaissance of Louisiana*, New Orleans (1873), p. 29.

[2] J. B. Robertson, "Exploration and Memorial of the Honorable J. B. Robertson in Relation to the Agriculture, Mining, and Manufacturing Resources of the State; with a Report of the Joint Committee," *Doc. Second Session, Second Legislature, Louisiana, Report No. 23*, 1867.

[3] *Op. cit.*

[4] A. C. Veatch, "The Salines of North Louisiana," *Geol. Survey of Louisiana, Report of 1902*, Special Paper No. 2 (1902), pp. 76–80.

Five wells have been drilled on this dome, as listed in Table IV.

These wells were all drilled on the north flank of the dome. Fee No. 1 reached rock salt at a depth of 161 feet, and Huckaby No. 2 at 2,228 feet; the others were abandoned in the cap rock.

TOPOGRAPHY

The central basin of King's salt dome (Fig. 13) is not so clearly outlined in the topography as the corresponding feature of some of the other salt domes of this region. On the west side a gentle slope merges into an extensive terrace which stands 40–60 feet above the central saline area. On the south and east sides Sparta sand forms the hills which rise to an altitude of more than 300 feet above sea-level and 150 feet above the saline basin. The salt dome is drained by Bayou Castor, flowing in a general southwesterly direction through the central low area. Minor streams empty into it from all directions.

TABLE IV

WELLS DRILLED ON KING'S SALT DOME

Company	Farm	Number	Location	Total Depth (Feet)	Year	Salt (Feet)
The Pardee Co......	Fee	1	35, 15 N., 8 W.	404	1914	161
The Pardee Co......	Fee	2	26, 15 N., 8 W.	....	1915	No
The Pardee Co......	Fee	3	26, 15 N., 8 W.	1,442	1915	No
Louisiana Oil Refining Corp.............	Huckaby	1	27, 15 N., 8 W.	2,232	1921	No
Louisiana Oil Refining Corp.............	Huckaby	2	27, 15 N., 8 W.	2,505	1921	2,228

SURFACE GEOLOGY

King's salt dome is near the line of contact of Cane River beds and Sparta sand. Sparta sand is well exposed in the hills flanking the dome on the east and southeast sides. Cane River beds crop out on the gentle slope between the central basin and the high hills. The Wilcox formation is represented in this area by two small outcrops, both on the south flank of the dome. The best Wilcox exposure is in the ditch on the west side of the highway, about 30 feet south of the bridge over Bayou Castor. It is a somewhat sandy, laminated, light-colored clay. This bed dips to the southeast at an angle of about 55 degrees. The Wilcox outcrop on Bayou Castor, near the northeast corner of Sec. 3, T. 15 N., R. 8 W., consists of laminated brown lignitic sand with thin streaks of dark lignitic clay.

An outcrop of limestone is reported in the bed of Bayou Castor, near the center of the SW. ¼ Sec. 35, T. 15 N., R. 8 W. Hilgard reports an outcrop of soft, fossiliferous, aluminous limestone, similar to the "rotten limestone" Mississippi, in the bed of Bayou Castor, and probably refers to the same outcrop which has since become covered.

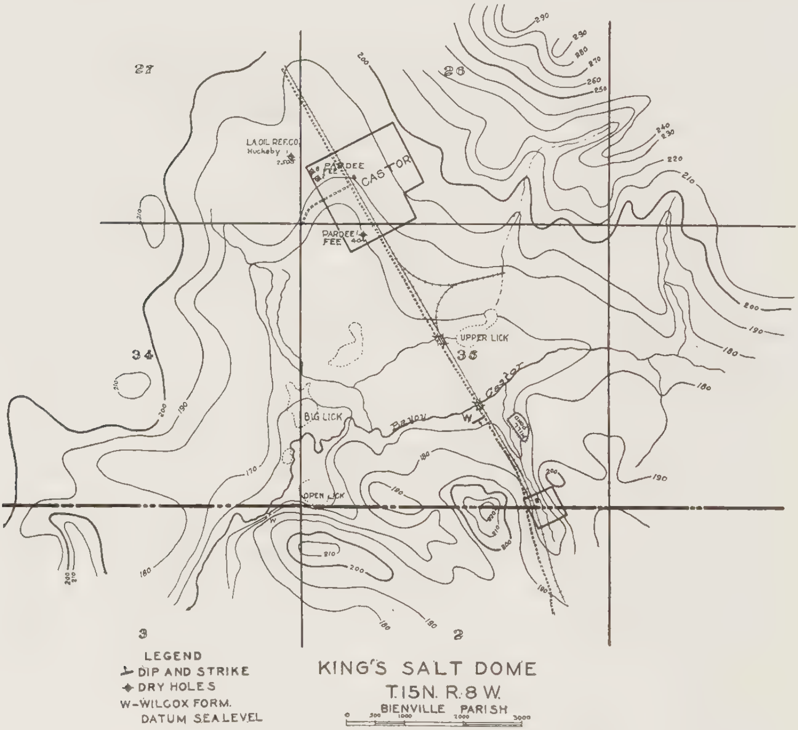

FIG. 13.—Topographic map of King's salt dome

Cretaceous beds penetrated in shallow brine wells sunk on the salt licks located on the outer margin of the central basin, together with the reported outcrop in Bayou Castor, indicate that Cretaceous beds of Marlbrook and younger age are present around the salt core but are generally concealed by the inwash of sand from the surrounding high hills.

UNDERGROUND GEOLOGY

Fragments of gray fossiliferous limestone collected by Veatch from the wall of King's old well contained the following species: *Exogyra costata*, *Lima pelagica*, *Anomia*, *Gryphaea vesicularis* var., *Turritella triliva*, *Liopistha protexta*(?).

A water well dug at Neal's store, just across the street from the railway station at Castor, showed the following section:

WELL SECTION, NEAL'S STORE[1]

	Feet
1. Yellow sandy clay mottled with white. Contains a few quartz pebbles	17
2. Very dark gray, sandy, laminated clay with *Ostrea larva* and *Ostrea* sp	4

The fossils obtained from these wells are of Upper Cretaceous age and probably should be referred to the Marlbrook formation.

Pardee Fee No. 1 found cap rock from 161 to 192 feet, and rock salt from 192 to the bottom of the hole at 404 feet. Pardee No. 3 was abandoned in the cap rock at a depth of 1,413 feet. As drill cuttings and cores are not available from these wells, only tentative correlations can be established. The Louisiana Oil Refining Corporation—Huckaby No. 1—started in the Midway formation and was abandoned in the cap rock at a depth of 2,232 feet. This well had a complete section, as shown in Figure 14.

The cap rock, so far as can be determined from the wells drilled to date, is only about 50 feet thick. It is similar in appearance to the cap rock cropping out at Winnfield, but is anhydrite and gypsum instead of calcite.

STRUCTURE

King's salt dome (Fig. 14) consists of a central salt core one-half to three-quarters of a mile in diameter, surmounted by a cap rock 50 or more feet in diameter. The Cretaceous rocks were sharply flexed and pierced by the intrusion of the salt core. The truncated edges of these sharply flexed beds, now generally covered by alluvium, are present around the periphery of the salt core. The

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[1] Data from A. C. Veatch.

Marlbrook, present at the surface on this dome, normally lies at a depth of 1,900 to 2,000 feet below the surface. The maximum vertical relief, therefore, is not less than 2,000 feet.

RAYBURN'S SALT DOME

LOCATION AND HISTORY

Rayburn's salt dome is located in the southeastern part of Bienville Parish. The center of the dome is in Sec. 35, T. 15 N., R. 5 W. It is 20 miles south of Arcadia dome and 5 miles northeast of Prothro dome.

The earliest record of salt-making at this locality dates from the early forties, when a Mr. Faust, owner of the land, commenced operation on a small scale. This work continued until the Civil War, when the federal blockade of the southern ports became effective and caused the salt to have a greatly enhanced value. In 1862 salt-making on a large scale commenced. A rent of $37\frac{1}{2}$ cents per bushel was charged for the privilege of making salt and for the wood consumed. The receipts of the owner of the land at this rate are said to have amounted to $375 a day. This would give a daily production of about 1,000 bushels. Sampson Rayburn, who married a daughter of Faust, was placed in charge and collected the rent. It was in this way that the lick became known as Rayburn's.

At the close of the war the works were almost abandoned. Occasionally a small amount of salt was made for local consumption as late as 1877.

This locality was described by Hilgard,[1] in 1873, and by Lerch,[2] in 1893, who reported the occurrence of *Exogyra costata*, thus adding to the proof of the existence of Cretaceous rocks in Louisiana. Rayburn's was described by Harris and Veatch[3] in 1899, and an excellent topographic map of this locality is shown by Veatch[4] in his comprehensive report of 1902 describing this locality in detail.

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[1] E. W. Hilgard, *Supplementary and Final Report of a Geological Reconnaissance of Louisiana*, New Orleans, 1873.

[2] Otto Lerch, "A Preliminary Report upon the Hills of Louisiana South of the Vicksburg, Shreveport & Pacific Railroad," *Bull. Louisiana Experiment Station, Geol. and Agri.*, Part II (1893), pp. 72–73.

[3] G. D. Harris, and A. C. Veatch, "A Preliminary Report on the Geology of Louisiana," *Geol. Survey of Louisiana, Report of 1899* (1900), pp. 52–55.

[4] A. C. Veatch, "The Salines of North Louisiana," *Geol. Survey of Louisiana, Report of 1902*, Special Paper No. 2 (1902), pp. 71–75.

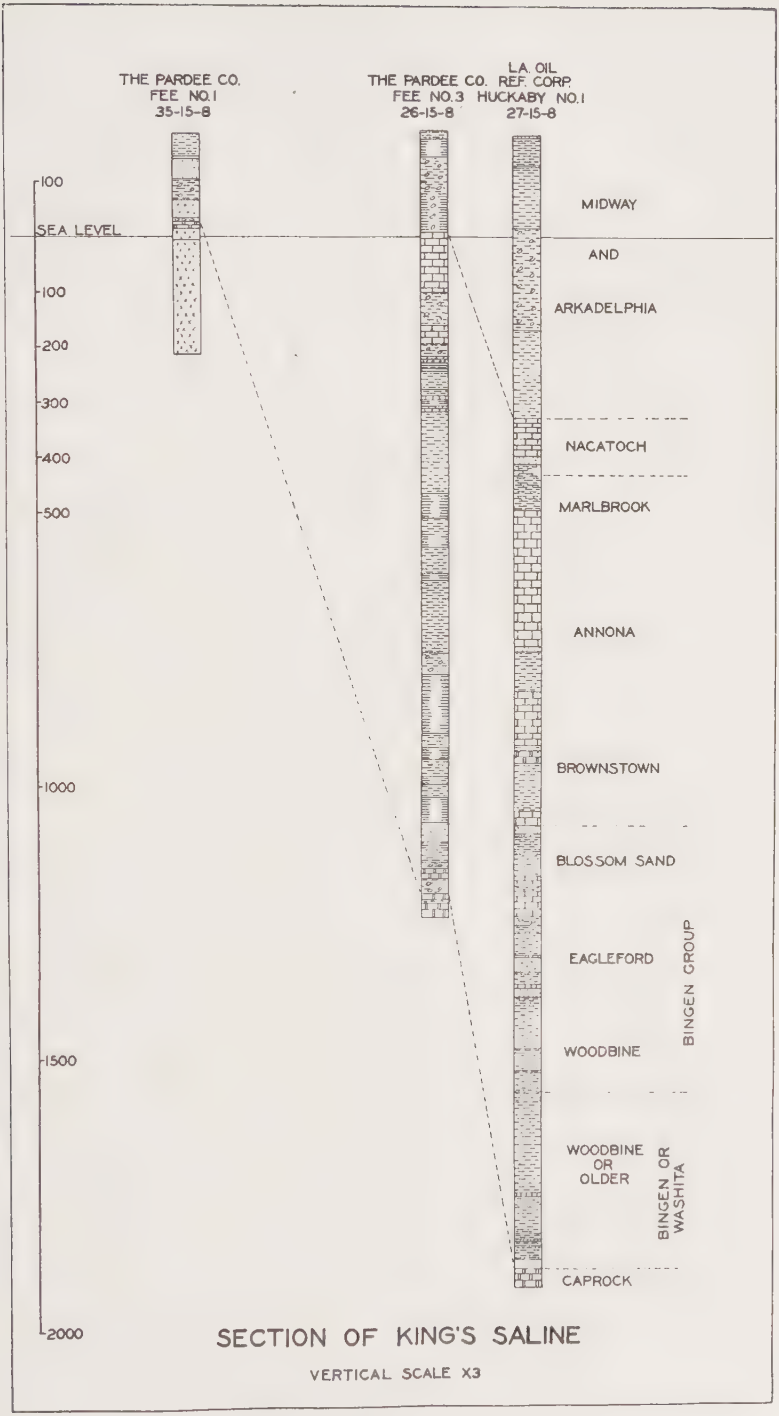


FIG. 14.—Well sections on King's salt dome

The old brine wells were shallow, usually 20–25 feet in depth. An attempt to develop this dome was made in 1910 by J. L. Dormon and associates, who drilled two wells, both located near the center of the saline. Both wells were abandoned in the cap rock, one at a depth of 37 feet and the other at a depth of 85 feet. In September, 1923, the Hodge-Hunt Lumber Company drilled their Fee No. 2, in Sec. 29, T. 15 N., R. 5 W., to a depth of 3,003 feet. In December, 1923, the same company drilled Fee No. 3, located near the center of Sec. 31, T. 15 N., R. 5 W. This well had cap rock from 85 to 115 feet and rock salt from 115 to 277 feet, at which depth it was abandoned.

TOPOGRAPHY

Rayburn's is a typical example of a salt dome with a central saline encircled by hills. The dome (Fig. 15) consists of a central saline 2,000 feet in length and 1,500 feet in width at the widest place. It is a slightly swampy area with an altitude of 180 feet above sea-level. The southern end is somewhat lower and, during heavy rains, is flooded to a depth of two or three feet. Gently sloping hills, which at a distance of 4,000 to 5,000 feet away rise 60–100 feet above the saline, encircle it.

Radial streams fed by surface water and by springs empty into the saline from all directions. A part of this water flows over the surface to form Faust Creek at the south end of the saline, but a large part sinks into the sand and gravel overlying the cap rock, and finally finds its way into Faust Creek through underground channels.

The saline represents the highest part of the uplift, and closely outlines the extent of the salt core.

SURFACE GEOLOGY

Rayburn's salt dome is in the outcrop of the Sparta sand, but older rocks, including the Blossom sand of Cretaceous age, crop out at the surface on the edges of the central saline.

CRETACEOUS FORMATIONS

Blossom sand.—A small outcrop of Blossom sand appears in the old road near the SW. cor., SW. ¼ of NE. ¼ of Sec. 30, T. 15 N., R. 5 W. It is poorly exposed and deeply weathered, having the appearance of ferruginous sand. When freshly broken it is a greenish-gray calcareous sandstone, identical with the Blossom outcrop on Prothro dome. The several fossils collected from this outcrop definitely establish the correlation.

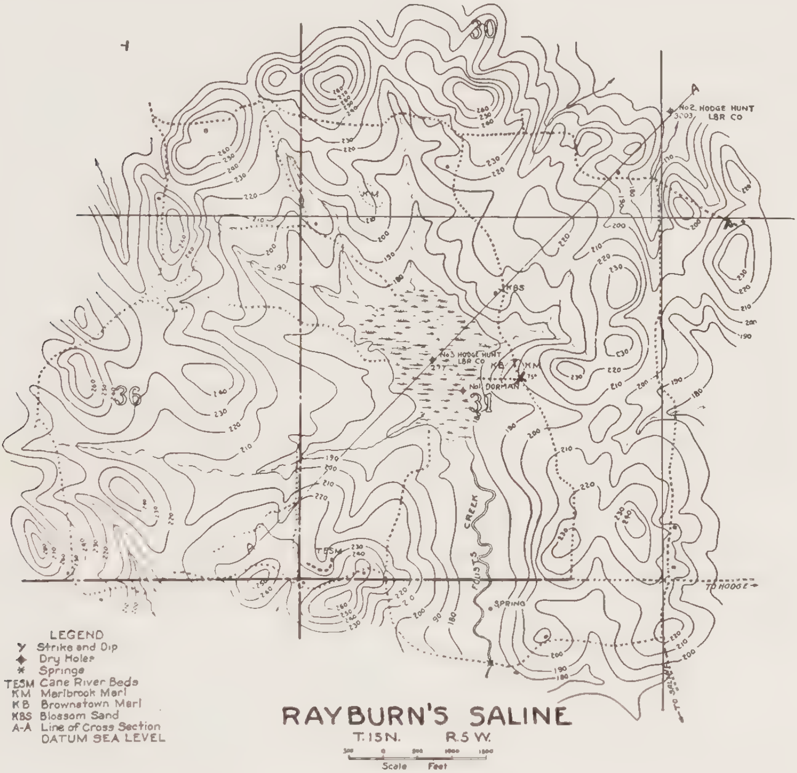


FIG. 15.—Topographic map of Rayburn's salt dome showing characteristic central saline encircled by hills.

Chalk and marl.—The Marlbrook formation and probably somewhat older beds crop out in two localities lying, respectively, north and east of the central saline. The outcrop on the east side shows about 500 feet of beds, consisting of fine-grained white chalk at the top and grayish-green to yellow-colored calcareous clay marls at the base. A thin bed of fossiliferous, sandy limestone is present at the base of the chalk. The chalk is highly fractured, and the fractures are often filled with calcite. The beds strike N. 30 E., and dip

75 degrees SE. The outcrop on the north is similar to that just described, except that a relatively greater thickness of clays and a less thickness of chalk is exposed. The beds dip about 65 degrees NE.

The calcite veins cutting the chalk strike N. 60 W. Fragments of celestite and barite are scattered over the surface around these outcrops, and a vein of barite, lying just above the chalk on the east side of the saline, has been traced about 150 feet, striking N. 10 E.

Chalk is reported from shallow wells on the west side of the saline, but the writer has had no opportunity to confirm this report.

The topography and the character of the residual soil indicate that the Cretaceous beds just described form a belt around the salt core. The Nacatoch and Arkadelphia formations have not been recognized on this dome, but are undoubtedly present under the residual sand from the encircling hills.

TERTIARY FORMATIONS

The older Tertiary, comprising the Midway and Wilcox formations and the Cane River beds of the Lower Claiborne group, are not well exposed on this dome, owing to the mantle of sand washed in from the encircling hills. Beds of Midway age were not recognized. The Wilcox crops out in several places, but is best exposed around Lowe's house and in the field east of the house in the SW. $\frac{1}{4}$ Sec. 30, T. 15 N., R. 5 W. It consists of light-colored and red ferruginous sand and sandy clays. The glauconitic clays, which are poorly exposed in the NE. $\frac{1}{4}$ Sec. 36, T. 15 N., R. 5 W., unquestionably belong in the Cane River beds, as do the fossiliferous, calcareous concretions found on the inner slope of the encircling hills in the SW. cor., Sec. 31, T. 15 N., R. 5 W. Sparta sand is well exposed in the hills and in the surrounding country.

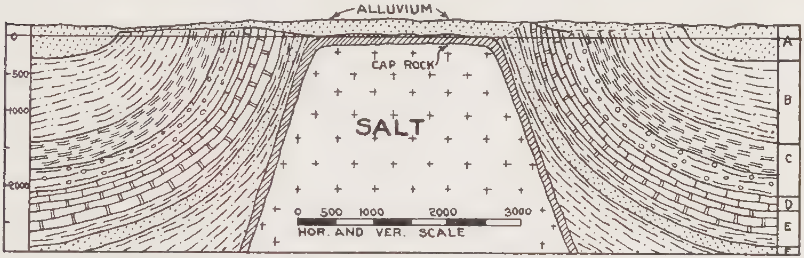
UNDERGROUND GEOLOGY

The old brine wells sunk on Rayburn's saline found cap rock after passing through a few feet of alluvium. The cap rock in the Hodge-Hunt Lumber Company—Fee No. 3 well—was 30 feet thick. The maximum thickness is probably somewhat greater. It consists chiefly of white- and gray-banded calcite rock, but gypsum and anhydrite are found in the walls of the old brine wells. Hodge-Hunt

Lumber Company—Fee No. 2 well, located 5,000 feet northeast of Fee No. 3—had a normal section. It was abandoned in the upper part of the Bingen at a depth of 3,003 feet.

STRUCTURE

An ideal section of Rayburn's salt dome is shown in Figure 16. This section is generalized and does not take into consideration faulting, which usually accompanies the intrusion of the salt core. This dome is believed to represent the typical development of the interior salt domes of northern Louisiana. It shows the pluglike form of the salt core, the piercing of the beds as the salt moved upward, the sharp flexing of the beds around the salt core, the deep truncation of the core, and the localization of the uplift.



A. Lower Claiborne. B. Wilcox Form. C. Midway and Arkadelphia formations.
D. Nacatoch formations. E. Chalk series F. Bingen group.

FIG. 16.—Cross-section of Rayburn's salt dome

PRICE'S SALT DOME

LOCATION AND HISTORY

Price's salt dome is located in northwestern Winn Parish, 6 miles northeast of Drake's and 12 miles south of Rayburn's salt domes. The center of the uplift is in Sec. 30, T. 13 N., R. 5 W. This dome is most easily reached by road from the station of Calvin on the Louisiana & Arkansas Railroad.

The first recognition of the locality is found on Tanner's[1] map of Louisiana, where it is marked "Salt Lick." The exact date of the first attempt to make salt here is not known. John Walker moved to this part of the country in 1859 and found old wells on the licks. Price's salt dome shared with other salt domes a period of intense activity during the Civil War, but records to show the daily production for this period are not available. The last attempt to make salt on any considerable scale was made by a man named Bynum, in 1869.

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[1] N. S. Tanner, Map of Louisiana, Philadelphia, 1820.

Price's salt dome was described in detail by Veatch[1] in 1902.

The old brine wells are shallow, usually 10–20 feet in depth. The Vivian Oil Company drilled their Bodcau No. 1, located near the center of the NW. $\frac{1}{4}$, Sec. 25, T. 13 N., R. 5 W., in 1916. This well was abandoned in the Blossom sand at a depth of 2,134 feet.

TOPOGRAPHY

The dominant topographic features of Price's salt dome (Fig. 17) is the central hill, Lick Hill, which is completely separated from the surrounding hill lands by the barren licks, or salines, encircling its base. The rolling, hilly lands on the west and southwest sides of the central hill reach an elevation of 180 feet above sea-level, or 95 feet above the salines and the bottom lands. On the north the hills are lower, and cut by the broad valley of Cypress Bayou. On the east side a narrow ridge, broken in three places by stream channels, separates the saline from the Dugdemona bottoms. The general features of Lick Hill are shown in Figure 17, but the several minor topographic features, notably the small holes, like sink holes, which are scattered over the hill, are but imperfectly represented. The largest of these holes is just south of the apex of the hill. It is about 75 feet in diameter and 20 feet deep.

The salt-dome region is drained by Dugdemona Bayou, which flows in a general southward direction on the east side of the dome. The salt dome proper is drained on the north by Cypress Bayou and on the south by Powder Spring Branch. Small radial streams rising on the flanks of the encircling hills on the west and south sides of the dome empty into the salines to form a circular drainage system around the base of Lick Hill.

SURFACE GEOLOGY

The hills encircling the dome are composed of light-colored and red sands and clays. Thin partings of ferruginous sandstone are not uncommon, and some clay ironstone occurs. The beds are generally massive, but in some places are poorly bedded. The upper parts of the hills are covered with fine gray sand, which generally conceals the structure of the underlying beds. The central hill is covered

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[1] A. C. Veatch, "The Salines of North Louisiana," *Geol. Survey of Louisiana, Report of 1902*, Special Paper No. 2 (1902), pp. 64–70.

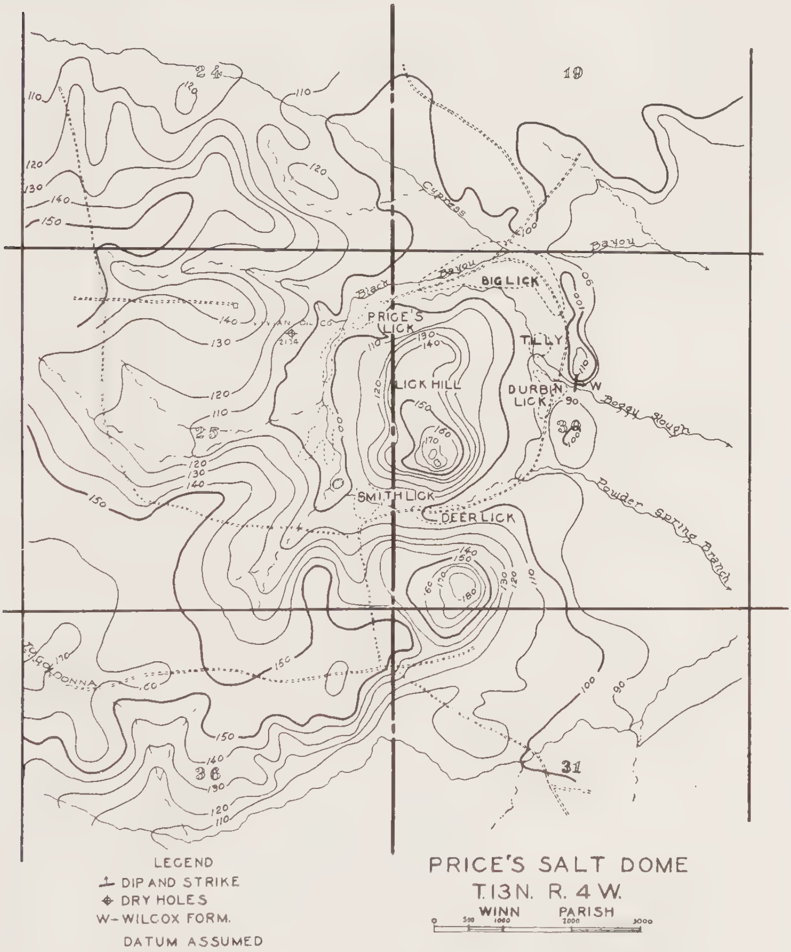

FIG. 17.—Topographic map of Price's salt dome, showing central hill with circular drainage system around the base.

with red sand, apparently residual, as several test pits show it to be underlain by light-colored sand and sandy clay, essentially similar to that exposed on the inner flanks of the encircling hills. A single outcrop of hard, light-gray, calcareous sandstone, containing leaf impressions and small particles of lignite, occurs on the inner slope of the low ridge facing Lick Hill on the east. It is almost identical in character and appearance with the outcrop at Rock Bluff, on Drake's salt dome. This outcrop is assigned to the Wilcox formation. It is small and poorly exposed; the strike appears to be north-south, and the dip is to the east. The beds outcropping on the inner flank of the encircling hills resemble the Wilcox formation, and the beds exposed higher on the hills and in the surrounding hill lands are typical Sparta sand. If this correlation is correct the marine, glauconitic, Cane River beds should outcrop in the hills, but the writer was unable to find them. The inwash of sand from the hills could easily have concealed them.

UNDERGROUND GEOLOGY

The shallow brine wells sunk on the salines, usually 10 to 20 feet in depth, penetrated silt, sand, and clay. Veatch[1] gives the following well section:

WELL SECTION, TILLY LICK

	Feet
1. Light sandy clay	2
2. Yellow clay mottled with red	5
3. Very dark blue clay	3

The dump heaps show fragments of calcareous sandstone similar to the outcrop previously described, as well as fragments of hard blue limestone resembling the calcareous bowlders of the Wilcox formation. Hilgard[2] reports the finding of vivianite, a mineral commonly associated with salt-dome cap rock. The well drilled on the west side of the dome by the Vivian Oil Company showed the following log:

LOG OF THE VIVIAN OIL COMPANY—BODCAU NO. 1,
IN SEC. 25, T 13 N., R 5 W.

	Depth (Feet)
Lignite	59
Fine packed sand and bowlders	84
Soft gumbo	85
Good fresh water show, water sand	104
Hard gumbo	110

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[1] *Op. cit.*, p. 68.

[2] E. W. Hilgard, *Supplementary and Final Report of a Geologic Reconnaissance of Louisiana* (New Orleans, 1873), p. 31.

	Depth (Feet)
Packed sand	122
Lignite, harder	134
Packed sand	146
Shale	149
Dolomite	166
Sandy shale	173
Dolomite	175
Blue flint rock	179
Sandy shale, packed	253
Rock, gas show	296
Packed sand	314
Fresh water sand	336
Lignite	342
Sandy shale	389
Mucky shale	428
Rock	431
Soft gumbo and bowlders	454
Hard packed sand	483
Shale and bowlders	506
Shale and bowlders	510
Packed sand	519
Soft gumbo	558
Rock with pyrite	560
Shale	570
Sandy shale and bowlders	594
Rock and pyrite	595
Soft gumbo	605
Rock	614
Sandy shale and bowlders	646
Rock and pyrite	647
Sandy shale	657
Rock	671
Coarse packed sand	675
Rock and pyrite	679
Sandy shale	698
Packed sand	733
Soft rock	737
Soft shale and gumbo	773
Gumbo, shale, bowlders, show of gas	804
Rock and pyrite, broken	814
Shale and bowlders	817
Salt water sand	823
Rock and pyrite	826
Sand rock with salt water	849
Lignite	857
Sandy shale	877
Rock and pyrite	887

	Depth (Feet)
Soft gumbo	899
Lignite	905
Rock and pyrite, soft and porous in places	913
Rock and pyrite, porous	917
Rock and pyrite	931
White sand and bowlders	947
Soft shale and bowlders	967
Hard gumbo	978
Rock and pyrite	979
Hard shale and bowlders	1,009
Rock and pyrite	1,013
Hard shale and bowlders	1,033
Rock and pyrite	1,035
Rock and pyrite	1,060
Hard shale	1,077
Rock and pyrite	1,081
Lignite	1,255
Hard shale and bowlders	1,494
Hard gumbo	1,505
Soft white rock	1,511
Gumbo	1,539
Hard shale	1,554
Hard gumbo	1,689
Rock	1,693
Hard shale	1,696
Chalky rock	1,699
Chalky rock, hard	1,946
Gumbo	1,953
Hard shale	1,971
Hard gumbo	1,988
Rock	2,029
Sand rock	2,091
Gumbo	2,104
Sand rock	2,134

Drill cuttings and cores are not available from this well, but an examination of the cuttings in the slush pit and around the casing head shows many fragments of chalk, *Inoceramus* prisms, and dark-colored shale, proving beyond reasonable doubt that the chalk was penetrated in this well. The sand recorded in the log, from 2,030 feet to the bottom of the hole at 2,134 feet, is probably the Blossom sand (Upper Bingen).

The sink holes on Lick Hill indicate a bed of soluble material beneath the surface sand. Test pits sunk to a depth of 40 feet found only sand and sandy clay, but that cap rock and rock salt underlie it at a moderate depth would seem a reasonable presumption.

STRUCTURE

The massive or poorly bedded sand and sandy clays exposed around this dome give no clues to the dips of these beds. The Blossom sand, found at a depth of 2,030 feet in the Vivian Oil Company's Bodcau No. 1, normally lies at a depth of 3,100–3,200 feet, indicating an uplift of more than 1,000 feet. As this well was drilled on the flank, the total uplift probably is considerably greater.

The salt licks or salines encircling the central hill perhaps closely outline the extent of the cap rock.

DRAKE'S SALT DOME

LOCATION AND HISTORY

Drake's salt dome is located in Winn and Natchitoches parishes. The center of the uplift is in Secs. 20 and 21, T. 12 N., R. 5 W. It is 6 miles southwest of Price's and 12 miles northwest of Winnfield salt domes. The town of Goldonna is one mile west of the dome.

According to the early settlers, the Indians made most of their salt at the Little Lick, and this statement is substantiated by the large accumulation of pot-shreds present about this lick. The salt at this locality was mentioned in the *Journal* of M. de Bienville,[1] of March 22, 1700, and many other references to this locality are found in the accounts of the early history of northern Louisiana. The exact date when white men first made use of the salt springs is uncertain, but one of the first accounts was given by John Sibley,[2] in a letter to General Dearborn, dated Natchitoches, April 10, 1805.

The local demand so increased that in the early forties a certain Reuben Drake, who was then in possession and whose name the locality yet retains, attempted to obtain stronger brine by deep boring. Eight wells were drilled, one, near the milldam on the north side of the dome, to a depth of 1,011 feet. The others appear to have been from 100 to 200 feet deep. Artesian brine was found in each. In the deep well the pressure was sufficient to lift the water into a tank 35 feet above the top of the pipe. As the brine from this well was much weaker than that obtained from the shallower wells, it was not used to any extent. At the present time this well is flowing a small amount of salty water.

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[1] Grace King, *Sieur de Bienville* (New York, 1892), pp. 100–102.

[2] John Sibley, "Louisiana: An Account of the Red River and Country Adjacent," *American Register*, Vol. 4, pp. 49–67.

The property passed into the possession of M. J. C. Wells, who commenced to make salt in 1854. He used two wells, one on Little Lick and the other on Upper Lick. During the salt season he made from 30 to 40 bushels daily.

With the outbreak of the Civil War salt operations on a large scale commenced, and continued to the end of the war. No records of the production are available, but it was probably second only to that of Bistineau. At the close of the war, operations on any considerable scale ceased.

Drake's salt dome was described in detail in 1902 by Veatch,[1] who gives a very complete history of this dome.

The first deep well, Drake's artesian well, was drilled in 1864 and 1865, and Savage Brothers drilled two wells in 1906 and 1907 to depths of 2,262 and 1,510 feet, respectively (Table V).

TABLE V

WELLS DRILLED ON DRAKE'S SALT DOME

Company	Farm	Location	Total Depth (Feet)	Year	Salt (Feet)
Reuben Drake......	Old Artesian Well	21, 12 N., 5 W,	1,011	1864–65	No
Savage Brothers....	Test Well No. 1	21, 12 N., 5 W.	2,262	1906	900
Savage Brothers.....	Test Well No. 2	21, 12 N., 5 W.	1,510	1907	No

TOPOGRAPHY

The topography of Drake's salt dome (Fig. 18) is of the type common to most of the domes of this region. The central basin is about one mile in diameter, and, except for a low ridge on the west side, it is a low, swampy area which, during high water, is entirely covered with water. The barren salt licks are distributed around the margin of the basin. The salt licks are encircled by gently rolling hill land, 30 to 40 feet higher than the salines.

Hickory Nut Ridge, on the southeast side of the dome, rises 100 feet above the general level of the surrounding country, and, together with the central saline area, is the outstanding topographic feature of this locality.

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[1] A. C. Veatch, "The Salines of North Louisiana," *Geol. Survey of Louisiana, Report of 1902*, Special Paper No. 2 (1902), pp. 51–64.

The salt dome is drained by Saline Bayou, flowing southward through the center of the dome. Cole Branch on the east and Malladoe Branch on the west side are the most important tributaries.

SURFACE GEOLOGY

The hills surrounding Drake's salt dome are composed of Sparta sand, which is normally at the surface here. Wilcox beds outcrop on Malladoe Branch, Cole Branch, and at Rock Bluff on Saline Bayou. Rocks of Cretaceous age are not known at the surface in this locality.

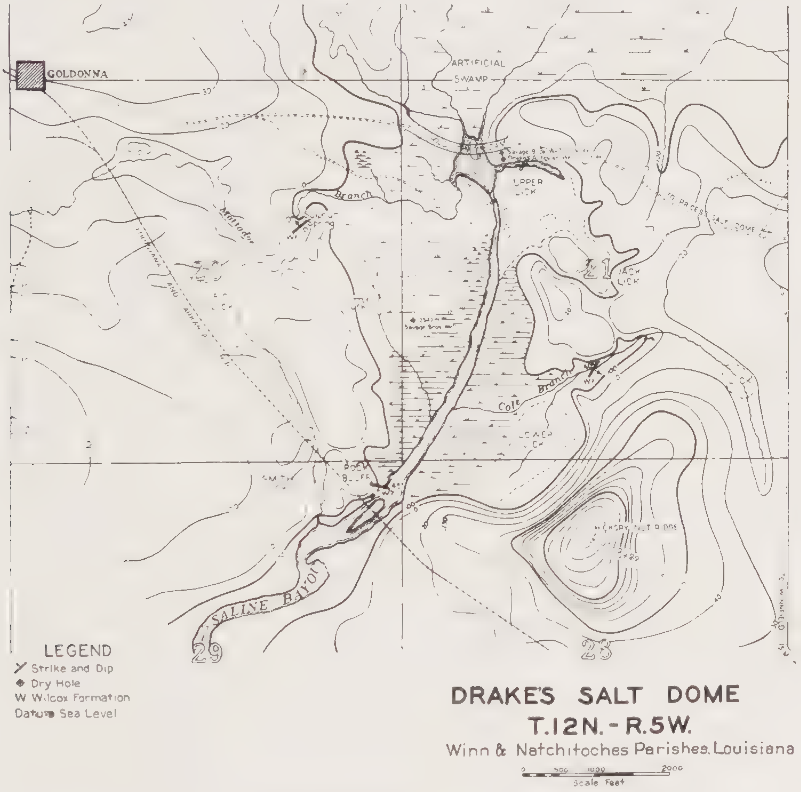

FIG. 18.—Topographic map of Drake's salt dome

The most important outcrop is at Rock Bluff, in the NE. cor., Sec. 29, T. 12 N., R. 5 W., where a gray, granular, calcareous sandstone containing leaf impressions, thin streaks of lignite, calcite in thin veins, and nodules of pyrite is exposed. The length of the outcrop is about 75 feet, and about 40 feet of beds are exposed at low water. Lithologically it is similar to the calcareous sandstone at Coochie Brake. The beds strike N. 80 W., and dip 45 degrees SW. A similar, but smaller, outcrop on Cole Branch strikes N. 56 E., and dips 40 degrees SE. On Malladoe Branch, near the center of the NE. $\frac{1}{4}$ of Sec. 20, T. 12 N., R. 5 W., is a small outcrop of gray, laminated sandy clay, dipping 10 degrees NW. These outcrops are assigned to the Wilcox formation, but, in the absence of fossils, their exact age is not definitely established.

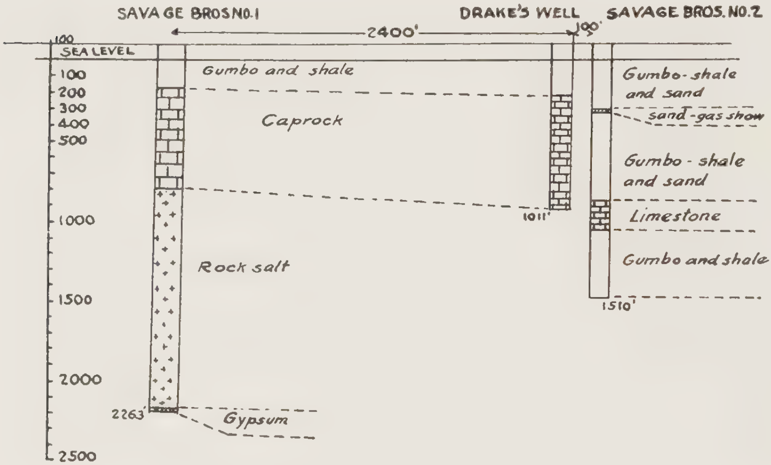

FIG. 19.—Well sections on Drake's salt dome

UNDERGROUND GEOLOGY

Graphic sections of the wells drilled on Drake's salt dome are shown in Figure 19. Drake's artesian well, drilled in 1864 and 1865, was reported by Hilgard,[1] and the following partial section is given by Veatch:[2]

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[1] E. W. Hilgard, *Supplementary and Final Report of a Geologic Reconnaissance of Louisiana*, New Orleans, 1873.

[2] A. C. Veatch, "Underground Water Resources of Northern Louisiana and Southern Arkansas," *U. S. Geol. Survey, Prof. Paper 46* (1906), p. 300.

PARTIAL SECTION OF TEST WELL AT DRAKE'S SALT WORKS, SEC. 21, T. 12 N., R 5 W.

	Feet
1. Yellow sand clay	0– 5
2. White sand	5– 42
3. Cypress log, very much decayed and charred on each side	42– 43
4. Soft sand and streaks of clay of various colors	43–318
5. Very porous crystalline limestone; crevices filled with white and yellow calcite crystals	318–475
6. According to Hilgard, cap rock continued to bottom of hole, at	1,011

Savage Brothers' Test Well No. 1, located in the center of the saline, had sand, gumbo, and shale to 290 feet, cap rock from 290 to 900 feet, and rock salt from 900 to 2,260 feet. It was abandoned in hard gypsum at a depth of 2,260 feet. Savage Brothers' Test Well No. 2, located about 100 feet from Drake's well, had sand, gumbo, and shale to 955 feet, limestone from 955 to 1,135 feet, and gumbo and shale from 1,135 feet to the bottom of the hole at 1,510 feet. As neither drill cuttings nor cores are available from this well it is not possible to establish the correlation of the beds penetrated, but the 180 feet of limestone found is probably of Nacatoch or Marlbrook age. Savage Brothers' Well No. 1 had 610 feet of calcite cap rock, identical with the cap rock which outcrops on Winnfield Quarry dome. This well was abandoned after drilling hard gypsum from 2,260 to 2,263 feet.

STRUCTURE

Drake's salt dome consists of a central salt mass, roughly circular in form, and $\frac{1}{2}$–$3\frac{1}{4}$ miles in diameter. The salt mass is overlain by calcite cap rock 600 feet or more in thickness on top of the dome, and presumably decreasing in thickness down the sides of the salt core. The lowering of the salt core, brought about by the removal of salt in solution, has caused the central basin, which is a conspicuous feature of the topography of this dome. As this area was lowered it was partially filled with alluvium, washed in from the surrounding hill lands, which has covered the truncated edges of the older rocks tilted up around the salt core. The Wilcox beds, exposed at Rock Bluff and other places, dip away from the center of the dome at the rate of 10 to 45 degrees. The probable structure of the salt core and cap rock and the attitude of the sedimentary strata are shown in Figure 20. The total vertical uplift of this dome cannot be determined, but, judging from stratigraphic evidence, it is estimated to be not less than 2,000 feet.

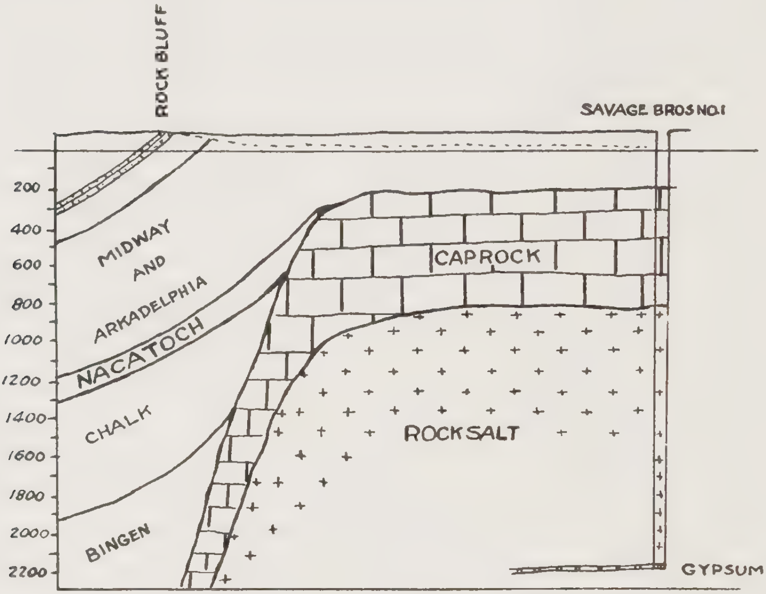

FIG. 20.—Section A-A[1] showing probable structure Drakes salt dome

THE WINNFIELD SALT DOME

LOCATION AND HISTORY

Winnfield salt dome is 4 miles west of the town of Winnfield, Winn Parish. The center of the dome is in Secs. 19 and 30, T. 11 N., R. 3 W. It is 8 miles northwest of Cedar Creek and 12 miles southwest of Drake's salt dome.

The Winnfield dome has been known for many years, and it is reported that limestone was quarried and burned for lime at this place long before the Civil War. The locality was described by Hilgard[1] in 1873. Harris and Veatch[2] described the geology in 1899, and pointed out the quaquaversal structure associated with this and other salt domes of northern Louisiana. Harris,[1] in 1907, described this area in more detail.

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[1] E. W. Hilgard, *Supplementary and Final Report of a Geologic Reconnaissance of Louisiana*, New Orleans, 1873.

[2] G. D. Harris and A. C. Veatch, "A Preliminary Report on the Geology of Louisiana," *Geol. Survey of Louisiana, Report of 1899*, Part V (1900), pp. 56–59.

At the present time limestone is quarried, and a crushing plant with a daily capacity of about 1,000 tons is in operation. J. T. Lyons, Jr., of New Orleans, Louisiana, estimates that a million tons of rock have been removed to date.

Drilling for oil and gas began in 1914, when the Tampico Oil Company drilled to a depth of 2,112 feet in Sec. 19, T. 11 N., R. 3 W., on the north side of the dome. The following list (Table VI) shows the wells drilled on and around this dome.

TABLE VI

WELLS DRILLED ON WINNFIELD SALT DOME

Company	Farm	Number	Location	Total Depth (Feet)	Year	Salt (Feet)
Tampico Oil Co....	Southern Mineral Co.	1	19, 11 N., 3 W.	2,112	1914	No
Cady Petroleum Co.	Southern Mineral Co.	1	19, 11 N., 3 W.	1,100	1920	999
Cady Petroleum Co.	Southern Mineral Co.	2	24, 11 N. 4 W.	1,246	1920	No
Gulf Refining Co...	Southern Mineral Co.	1	30, 11 N., 3 W.	4,021	1921	No

The Tampico Oil Company and the Gulf Refining Company wells found cap-rock material at several different depths, but salt was not encountered.

TOPOGRAPHY

The altitude of the bottom land along Bayou Sonnett, on the north side of the dome, is 140 feet above sea-level, and that of the highest hills in the locality is 260 feet, giving a total relief of 120 feet. The central part of the dome, represented by the outcrop of calcite cap rock, is slightly basin-shaped, being 60-80 feet lower than the rim of hills encircling it on all but the north side. This rim of hills, sloping steeply toward the center of the dome, although no higher than the hills farther away from the center of the uplift, is nevertheless a marked feature of the topography of the dome (Fig. 21). The hills owe their presence to a capping of hard, ferruginous sandstone in the St. Maurice beds.

The regional draining is through Bayou Sonnett, which rises several miles to the northwest. It flows in a general northeasterly direction until near the west side of the dome, where it follows the periphery of the uplift to the center of Section 19, where it again changes its direction to northeast and empties into Port Luce Creek. Rocky Branch, which rises near the center of the SW. ¼ of Sec. 30, drains the salt dome. It flows northeast, along the cap rock outcrop, and empties into Bayou Sonnett near the center of Sec. 19, T. 11 N., R. 3 W.

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[1] G. D. Harris, "Notes on the Winnfield Sheet," *Geol. Survey of Louisiana, Report of 1907*, Bull. No. 5 (1907).

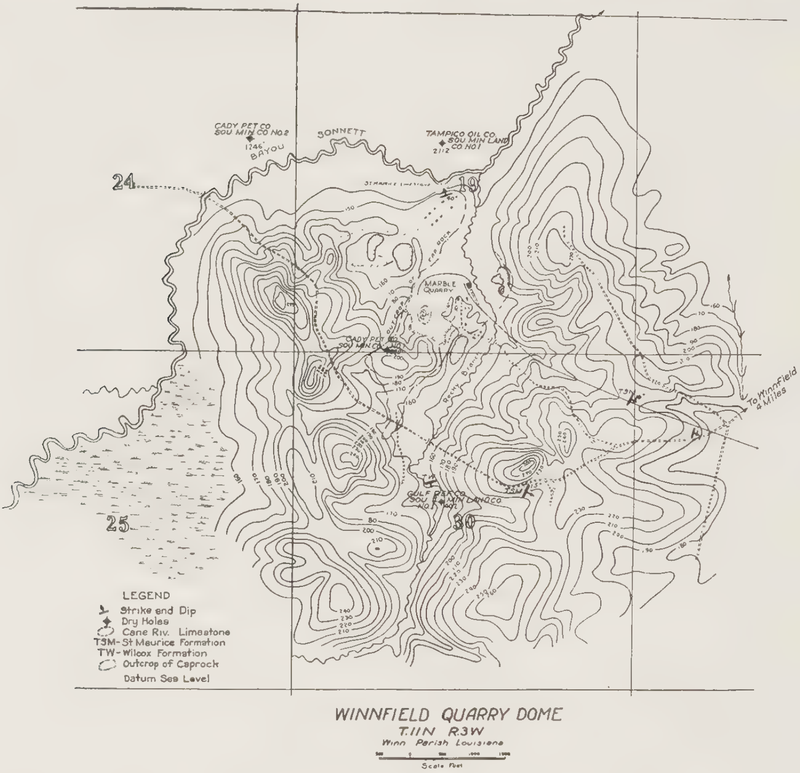

FIG. 21.—Topographic map of Winnfield Quarry dome

An interesting feature is present in the low, marshy area lying between the encircling hills and Bayou Sonnett on the southwest side of the dome. This area is densely covered with trees, and its true nature has not been ascertained, but it is believed to represent an old course of the bayou in an earlier attempt to encircle the dome on the south side.

Many springs are present on the inner flanks of the encircling hills.

SURFACE GEOLOGY

Winnfield salt dome lies a short distance south of the contact between the St. Maurice beds and the Yegua formation. The encircling inner rim of hills is composed of sand, clay, and ferruginous sandstone belonging to the St. Maurice beds and the Sparta sand of the Claiborne group. The Cane River beds are represented by a small outcrop on the north side of the dome, and the Wilcox formation is recognized in two small isolated exposures. The outstanding feature of the dome is the exposure of the calcite cap rock over a considerable area in the center of the uplift. Cretaceous rocks have not been recognized in this locality.

Cap rock.—The highest part of the dome is represented by an outcrop of calcite cap rock, covering an area of about 120 acres, in Secs. 19 and 30, T. 11 N., R. 3 W. That this limestone is more extensive than the surface outcrop is indicated by the sink holes present on the east and west sides of the outcrop. In the quarry face, 70 feet of limestone is exposed, but its total thickness is about 1,000 feet, as shown by the following well record:

DESCRIPTION OF SAMPLES FROM CADY PETROLEUM COMPANY— SOUTHERN MINERAL COMPANY NO. 1, SEC. 19, T. 11 N., R. 3 W.

	Depth (Feet)
Limestone, white and bluish-gray, many small pockets of calcite crystals evident	125
Very small fragments of grayish-blue banded marble	236
A very fine white water sand	300–303
Marble, grayish-blue; fine to rather coarse material	314
Gray to dark marble	320
Marble, white and blue	326
Fine, white sand	326–334
White and blue-banded marble, predominantly white in color. One fragment contained a very small pocket of sulphur, burning readily and giving characteristic fumes	334–367
White to gray and blue-banded marble	367–386
White and blue-banded marble	391–409
Blue-banded marble, together with much fine to medium-textured white to colorless sand	409–419
Gray and blue-banded marble; some pieces of white calcite	432–436
Very fine, white, calcareous sand	436–438
White and blue-banded marble	438–999

The cap rock from the dome is described by M. I. Goldman, of the U. S. Geological Survey, as follows:

Hand specimen.—A very coarsely crystalline white limestone with thin fine-grained gray bands, partly very continuous and partly very twisted, shattered, faulted, or discontinuous, as if the material of the rock had been rearranged with some displacement. Full of cavities of varying size up to one-half inch, elongated parallel to the bedding, into which terminated crystals project. Orange-brown impurities along the walls of the cavities.

Thin section.—Very large calcite crystals which, at extinction, have a mottled and flecked appearance; the flecks have a distinct fibrous appearance, with the orientation in two directions. By immersion of crushed material of the rock in a liquid of index equal to that of calcite these are found to be not inclusions, but planes developed in the rock presumably by pressure. Inclusions, on the contrary, are very scarce, and consist mostly of small dirty granules, probably argillaceous. At one point a small fragment of what appeared to be anhydrite was seen lying between calcite grains. The black bands are found to consist of fine-grained matter of argillaceous texture, disseminated in and around the calcite crystals apparently with little regard to present crystal boundaries. The crystals in these bands are generally somewhat finer, but the bands are not sharply defined, either in form or character.

Residue insoluble in acid.—Treatment with cold dilute hydrochloric acid leaves a small residue (perhaps $\frac{1}{2}$ per cent) which is found to consist mostly of barite, with perhaps a little anhydrite and celestite. The majority of the grains are full of small black inclusions which suggest that they come mainly from the gray bands. Numerous very perfect, doubly terminated small (about 0.05 to 0.1 mm.) quartz crystals occur, evidently formed in place.

N. Bawles, of Winnfield, Louisiana, has furnished the following analysis of the cap rock:

QUANTITATIVE ANALYSIS

	Percentage
Silica as SiO_2	1.25
Iron and Alumina	1.50
Calcium as CaO	56.95
Magnesium as $MgL.P_2O$	1.20
Sulphates	0.82
Loss on heating (carbon dioxide)	35.00

COMBINING RESULTS

	Percentage
Calcium carbonate ($CaCo_3$)	85.33
Calcium oxide (CaO)	9.18
Silica (SiO_2)	1.25
Iron and Alumina (Fe and Al)	1.50
Magnesium (Mg)	1.20
Sulphates	0.82

Loss at 120 degrees very small

The fine exposure of the unweathered cap rock in the 70-foot quarry face gives a good idea of the irregularity of the blue-gray banding which changes laterally, in a distance of a few feet, from the width of pencil marks to bands more than one inch in width. The highly fractured condition of this limestone mass is also well illustrated here.

EOCENE FORMATIONS

Wilcox formation.—This formation is not well exposed, but is probably present in many places around the periphery of the cap rock, where it is generally concealed by the inwash of sand from the surrounding hills. Two outcrops, one on the north side and one on the south side of the cap rock outcrop, are correlated with the Wilcox formation. The outcrop on the north side lies under the Claiborne limestone, where 30 to 40 feet of laminated, chocolate-colored and brown lignitic clay, striking about N. 80 E. and dipping NW., is assigned to the Wilcox formation. It contains a number of species of fossil plants. The other outcrop is in the bank of Rocky Branch near the center of Sec. 30, T. 11 N., R. 3 W. It consists of finely laminated lignitic clay which apparently dips to the southeast.

Cane River beds.—The basal beds of the Claiborne group are represented by a small outcrop near the center of Sec. 19, T. 11 N., R. 3 W. It consists of light-colored, somewhat glauconitic, highly fossiliferous limestone and glauconitic marly clay. The length of the outcrop is about 300 feet, and about 30 feet of beds are exposed. The beds strike N. 30 E., and dip 30 to 40 degrees NW.

Sparta sand.—The light-colored sands and sandy clays that appear on the inner flank of the hills encircling the cap rock outcrop belong to the Sparta-sand member of the Lower Claiborne. They are particularly well exposed in the old St. Maurice-Winnfield road, on both sides of Rodly Branch, in Sec. 30, T. 11 N., R. 3 W.

St. Maurice beds.—These beds, consisting of thin glauconite sand and marl beds interbedded with light-colored sand and sandy clay, containing a considerable amount of ferruginous sandstone, outcrop in the upper part of the encircling hills. They are well exposed along the quarry railroad and in the St. Maurice-Winnfield road. Dips of 10 to 15 degrees are observed.

Yegua formation.—The light-colored sand and lignite clays which make up this formation are well exposed in the area surrounding the dome. Dips of 1 to 3 degrees are noted.

UNDERGROUND GEOLOGY

Drill cuttings and cores are available from only two of the four wells drilled in this locality (Fig. 22). The Cady Petroleum Company—Southern Mineral Company No 1—started in the cap rock and continued in this material to 990 feet, where rock salt was encountered. It was abandoned in rock salt at a depth of 1,100 feet. The Gulf Refining Company—Southern Mineral Company No. 1—started in the Claiborne and at a depth of 4,012 feet was in the Arkadelphia formation of the Upper Cretaceous. Limestone and anhydrite were encountered at several depths in this well. A core from 2,020 feet consisted of gray anhydrite showing a dip of 70 degrees. Sandy lime is recorded at various depths, from 290 feet down to 1,800 feet. From the appearance of this material in the drill cuttings the lime is believed to be secondary. The Tampico Oil Company—Southern Mineral Company No. 1—records sand and shale from the surface to a depth of 1,185 feet, and considerable marble from 1,185 to 1,600 feet.

CEDAR CREEK SALT DOME

LOCATION AND HISTORY

Cedar Creek salt dome is located about three miles south of Winnfield, in Winn Parish. The center of the dome is in Secs. 30 and 31, T. 11 N., R. 2 W. It is seven miles southeast of Winnfield Quarry dome. The Winnfield-Alexandria highway crossed the central saline.

A small amount of salt was produced during the Civil War from a well located on the salt lick, on the west side of the dome, south of the highway. This locality was described by Hilgard,[1] and described in detail by Harris,[2] who gives a section of the supposed structure of the rocks underlying Cedar Lick.

Drilling for oil and gas commenced in 1903 and continued, with many interruptions, to 1917. Inadequate drilling equipment and the hard cap rock material prevented the wells drilled on the higher portion of the dome from reaching any considerable depth. Pardee

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[1] E. W. Hilgard, *Supplementary and Final Report of a Geologic Reconnaissance of Louisiana* (New Orleans, 1873), p. 32.

[2] G. D. Harris, "Notes on the Winnfield Sheet," *Geol. Survey of Louisiana, Report of 1907*, Bull. No. 7 (1907), pp. 10–14.

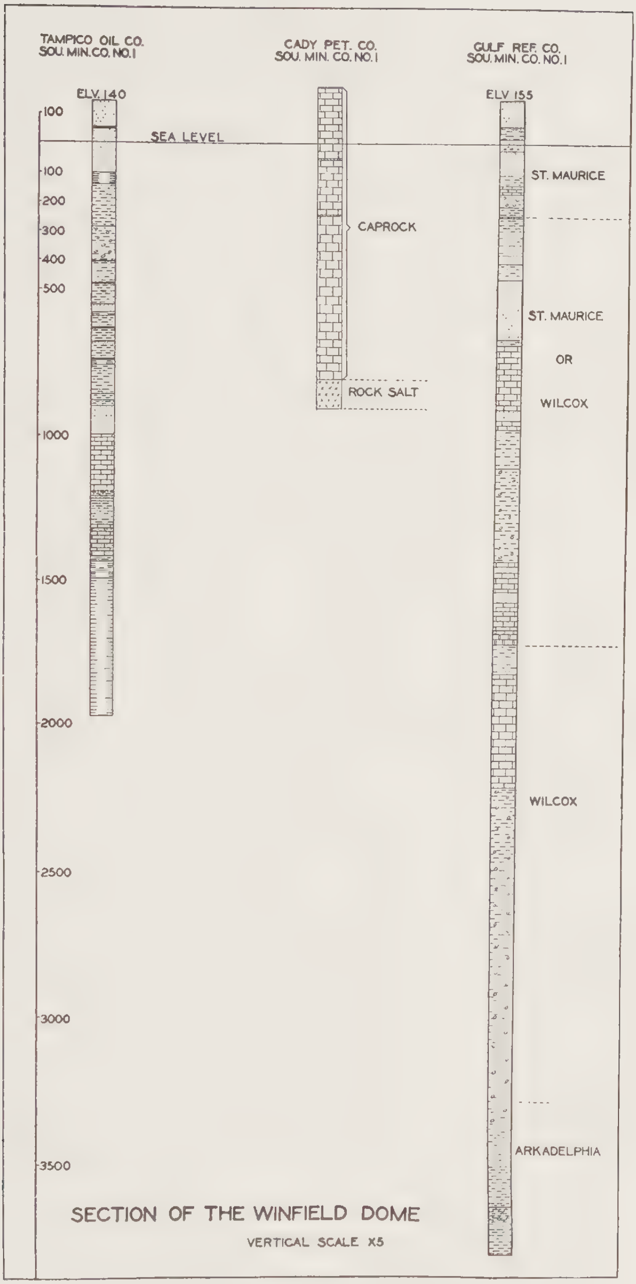

FIG. 22.—Well sections on Winnfield Quarry dome

No. 2 missed the cap rock and the salt and, as near as can be determined, was abandoned in the upper Bingen at 2,650 feet.

TOPOGRAPHY

The topography of Cedar Creek dome (Fig. 23) is very much like Drake's salt dome. It consists of a central saline basin over the salt mass, surrounded by a series of low hills. The central saline is a low, flat area about 6,000 feet long and 3,000 feet wide at the widest point. It is covered with trees, except on the barren salt licks, or salines, grouped around its periphery. The elevation is 100 feet above sea-level, and the relief of the encircling hills, which merge with the gently rolling hill land of this area, is 50–70 feet.

TABLE VII

WELLS DRILLED ON CEDAR CREEK SALT DOME

Company	Farm	Number	Location	Year	Depth (Feet)	Cap Rock (Feet)	Salt (Feet)
The Pardee Co.....	Fee	1	31, 11 N., 2 W.	1914	1,120	806	No
The Pardee Co.....	Fee	2	31, 11 N., 2 W.	1914	2,650	No	No
The Pardee Co.....	Fee	3	31, 11 N., 2 W.	1917	450	?	No
Pace *et al*..........	Pace	1	31, 11 N., 2 W.	1903–7	226–1,000	No	No
Pace *et al*..........	Pace	2	31, 11 N., 2 W.	1903–7	226–1,000	Yes	No
				1903–7	226–1,000		
Winnfield Oil Co...	Butler	.....	31, 11 N., 2 W.	1903–7	226–1,000	Yes	No
Winnfield Oil Co...	Clifford	.....	31, 11 N., 2 W.	1903–7	226–1,000	?	No

The salt dome is drained by Cedar Creek, which meanders northward through the low area. Radial drainage converges in the central basin.

SURFACE GEOLOGY

Cedar Creek dome lies in the area of the Yegua formation, which is exposed in the upper portion of the encircling hills. St. Maurice beds crop out along the highway in the SW. $\frac{1}{4}$ of Sec. 30, T. 11 N., R. 2 W., and probably crop out in a belt encircling the central saline, where they have been covered by the inwash of sand from the surrounding hills. Older Tertiary and Cretaceous rocks are not known to crop out in this locality.

UNDERGROUND GEOLOGY

The underground geology is difficult to interpret from the meager data obtained from the wells drilled in this locality. The cap rock is found from 600 to 800 feet below the surface. It consists of white and gray banded calcite rock, similar to the cap rock at Winnfield, but containing more gray material and much more pyrite. The considerable amount of pyrite contained in this rock accounts for the hard drilling met with on this dome. More than 300 feet of cap rock were penetrated in Pardee No. 1 well, and its total thickness may be several hundred feet more. The age of the

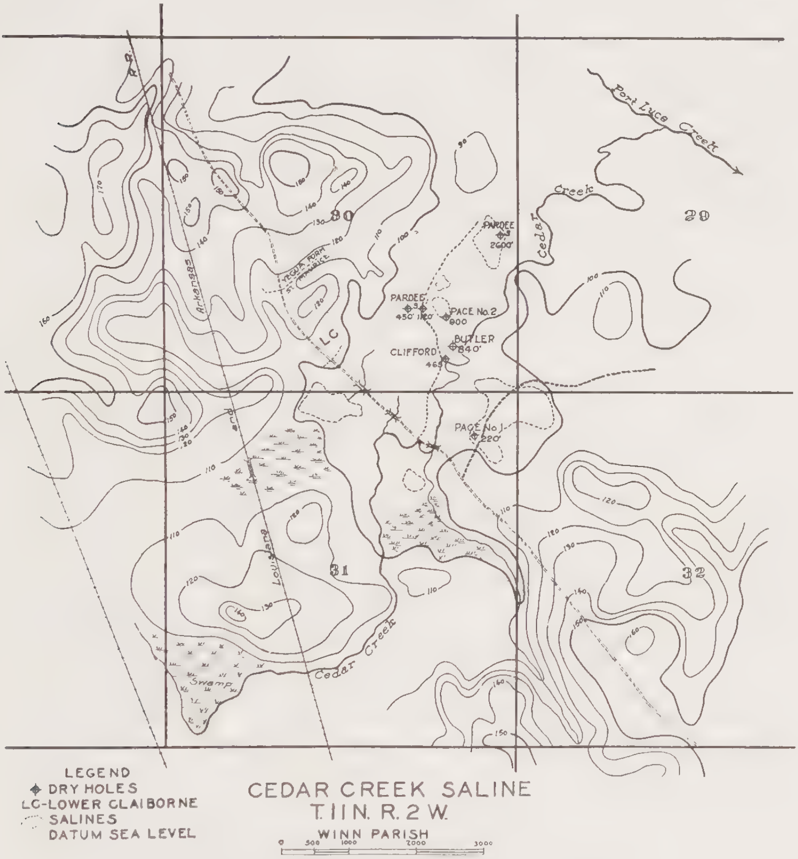

FIG. 23.—Topographic map of Cedar Creek salt dome

600–800 feet of beds overlying the cap rock is not known, but from the driller's record appears to be, in part at least, of Cretaceous age.

Pardee No. 2 well, drilled about 1,500 feet northeast of the No. 1 well, appears to have had a normal section, finding neither cap rock nor rock salt. As the writer interprets this log (Fig. 24) it had chalk from 1,952 to 2,206 feet and the top of the Blossom sand at 2,247 feet. The record is incomplete from 2,310 feet to the bottom of the hole at 2,650 feet. If this correlation is correct, an uplift of more than 3,000 feet is indicated.

STRUCTURE

The cap rock penetrated in several of the wells drilled on this dome proves beyond reasonable doubt that the salt mass underlies it at some depth. The steepness of the dip around the cap rock is indicated by the logs of Pardee No. 1 and Pardee No. 2 wells (Fig. 24). The vertical uplift measured on the Blossom sand, normally about 4,500 to 5,000 feet below the surface in this region, but found at a depth of 2,247 feet, is about 2,700 feet. The total vertical uplift is probably somewhat greater.

COOCHIE BRAKE

LOCATION AND HISTORY

Coochie Brake is located in the southwestern corner of Winn Parish, about 5 miles west of Atlanta and 15 miles southwest of Winnfield. The center of the brake, which is believed to coincide with the center of the uplift, is in Sec. 6, T. 9 N., R. 4 W. It is 8 miles southwest of Winnfield salt dome and 14 miles south of Drake's salt dome.

The limestone outcrop on the north side of Coochie Brake has been referred to by many of the early investigators of this region. Its chief interest to the layman seems to have been founded on the belief that precious minerals occurred in this locality. Harris and Veatch[1] believe that the glittering appearance of freshly broken pyrite nodules, which occur in this rock, have been at the bottom of the vast majority of statements concerning the mineral wealth of this part of Louisiana. Salt was not made at this locality, and it is therefore not so generally known as some of the other domes.

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[1] G. D. Harris and A. C. Veatch, "A Preliminary Report on the Geology of Louisiana," *Geol. Survey of Louisiana, Report of 1899* (1900), p. 60.

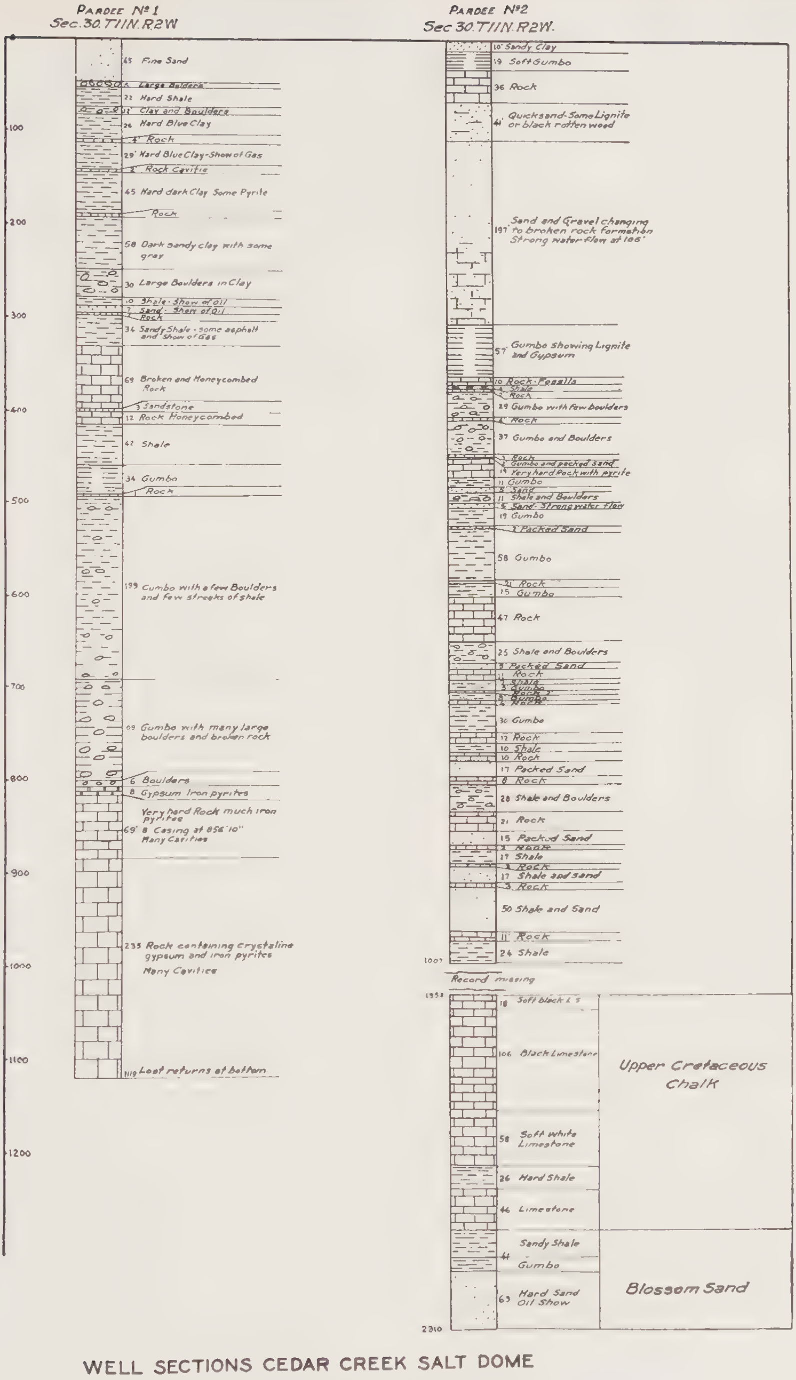

FIG. 24.—Well sections on Cedar Creek salt dome

Harris and Veatch[1] described Coochie Brake in 1899, and Harris,[2] in 1907, amplified his previous statements concerning this locality. These investigators first interpreted Coochie Brake as a structural dome.

The Cady Petroleum Company drilled two wells in 1921, both located in Sec. 31, T. 10 N., R. 4 W. Edenborn No. 1 was junked at a depth of 1,912 feet, and Edenborn No. 2 was abandoned as a dry hole at a depth of 3,100 feet. Neither well reached cap rock or rock salt, but the information obtained from these wells substantiated the presence of an uplift comparable in magnitude to that of other salt domes in this region.

TOPOGRAPHY

Coochie Brake (Fig. 25) is a somewhat swampy area which, during the greater portion of the year, is covered with 2–4 feet of water. It is slightly more than one mile in diameter. The brake and the surrounding area, except on the north side, are densely covered with timber and underbrush. The altitude of the brake is about 150 feet above sea-level, and that of the highest hills encircling it on the north is 75–80 feet higher. The most conspicuous topographic feature of this locality is the calcareous sandstone outcrop which forms a prominent northeast-trending ridge in the SW. $\frac{1}{4}$ of Sec. 31, T. 10 N., R. 4 W. This ridge rises precipitously to a height of 65 feet above the level of the brake. Because of dense vegetation, the area to the south of the brake is practically unknown. Salt and sulphur waters and gas emanations are not known to occur, but it is possible that they may occur in the unexplored portion of the area.

The existence of a salt core underlying Coochie Brake is not proved, but the evidence of an uplift approaching some of the better-known domes in magnitude is reasonably conclusive. A comparison of the topography of Coochie Brake with that of Drake's salt dome, 14 miles to the north, is suggestive. Coochie Brake corresponds closely in outline and areal extent to the central saline area at Drake's, and the calcareous sandstone, dipping steeply away from the dome, is present in both localities and occupies the same position relative to the central low area. The rock in both places is essentially similar in character.

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[1] *Op. cit.*, pp. 59–61.

[2] G. D. Harris, "Notes on the Winnfield Sheet," *Geol. Survey of Louisiana, Report of 1907.*

SURFACE GEOLOGY

The hills around Coochie Brake are composed of light-colored sands belonging to the Yegua formation of the Upper Claiborne.

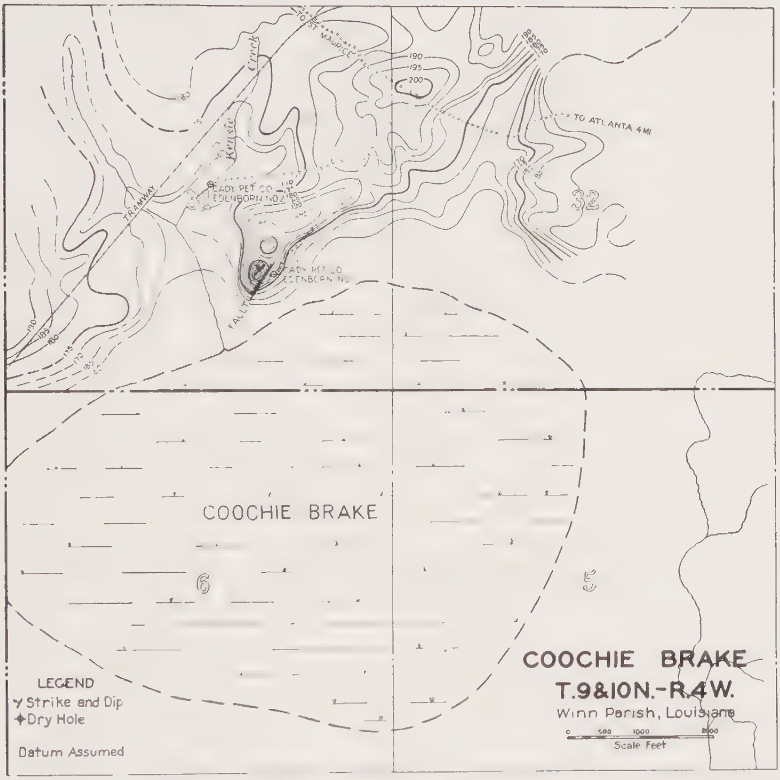

FIG. 25.—Topographic map of Coochie Brake

The slopes of the hills are covered with fine sand, effectually concealing any bedding that may be present. The only outcrop of importance in this locality is the ridge-forming limestone in the SE. $\frac{1}{4}$ of Sec. 31, T. 10 N., R. 4 W. The general features of this outcrop and its topographic expressions are shown in Figure 25. It is a massive calcareous sandstone containing many nodules of pyrite. Small fragments of lignite and some fossil leaves are found in these beds, which, except for the greater amount of pyrite, are almost identical with those exposed at Drake's and Price's salt domes. The beds strike northeast, and although no distinct bedding planes are present, the inclination is definitely to the northwest.

UNDERGROUND GEOLOGY

The two wells drilled by the Cady Petroleum Company in Sec. 31, T. 10 N., R. 4 W., have furnished some information relative to the underground geology. However, these wells are located well down the flank of the uplift and did not reach the Cretaceous. Edenborn No. 1 well was junked at a depth of 1,912 feet, probably in the lower Wilcox, which, on the outcrop in Sabine Parish, would correspond to the Nanafalia beds. Edenborn No. 2 well, located 1,100 feet northwest of Edenborn No. 1, was abandoned at a depth of 3,100 feet, probably in the base of the Wilcox formation or in the upper part of the Midway formation. Chester A. Baird, geologist for the Cady Petroleum Company, supervised the drilling of these wells. According to Mr. Baird, Edenborn No. 1, located at the base of the limestone escarpment, found the top of the calcareous sandstone at a depth of 121 feet below the top of the escarpment, indicating a fault of approximately the same displacement. The same calcareous sandstone bed was found in Edenborn No. 2, located 1,100 feet northwest of Edenborn No. 1, 481 feet below the top of the escarpment, indicating a dip to the northwest of more than 20 degrees.

STRUCTURE

The 20-degree northwest dip on the north flank of Coochie Brake dome is even more impressive when it is considered that this dome is on the steeply southward-dipping Angelina-Caldwell flexure. Presumably the older Tertiary and Cretaceous rocks approach, or reach, the surface between the brake and the limestone outcrop. The center of the uplift, or that part of the dome underlain by the salt core, lies somewhere within the low marshy area known as Coochie Brake.

BIBLIOGRAPHY

The more important publications relative to the salt domes and the stratigraphy of this region are here given in chronological order:

1850. C. G. Farshey, "Louisiana: Geology and Hydrography (Abstract of Lecture)," *DeBow's Review*, Vol. 8, 1850. Notable mainly for containing the following statement concerning the north Louisiana salt springs: "A saline bed seems to underlie the Tertiary beds generally."

1867. J. B. Robertson, "Memorial and Explorations of the Honorable J. B. Robertson in Relation to Agriculture, Mineral, and Manufacturing Resources of the State, with a Report of the Joint Committee," *Doc. Second Session, Second Legislature, Louisiana, Report No. 23,* 1867; also separate, New Orleans, 1867, 30 pages. This report contains the first mention of the Cretaceous in Louisiana. The writer records that at King's salt works there are 200 feet of fossiliferous Cretaceous limestone.

1869. E. W. Hilgard, "Summary Result of a Late Reconnaissance of Louisiana," *American Journal of Science*, 2d Ser., Vol. 47 (1869), pp. 78–88. Hilgard established the presence of the Cretaceous by fossils found at King's salt works. From the relative geographical position of the different outcrops around the salines he concluded that there was in Louisiana a Cretaceous backbone, or ridge, extending in a general northwest-southeast line. He believed that at the beginning of the Tertiary this axis of elevation was marked by a number of islands in the Tertiary sea, and that they were finally covered with deposits of the younger formations.

1870–72. F. V. Hopkins, *First, Second,* and *Third Annual Report, Geol. Survey of Louisiana* (New Orleans, 1870, 1871, and 1872). In these reports the author reviews the geology of the state and includes the first geological map of Louisiana. He also refers to the vertebrate fossil remains found on several of the north Louisiana salines.

1873. E. W. Hilgard, *Supplementary and Final Report of a Geological Reconnaissance of Louisiana* (New Orleans, 1873). This report contains a more detailed description of the salines than is contained in the earlier publication of the same title.

1892. Otto Lerch, "A Preliminary Report upon the Hills of Louisiana North of the Vicksburg, Shreveport & Pacific Railroad, *Bull. Louisiana State Exp. Station, Geol. and Agr.*, Part I, 1892. Lerch added to the proof of the Cretaceous age of certain outcrops at Rayburn's saline by finding *Exogyra costata.* He held that about the close of Cretaceous time extraordinary disturbances took place which resulted in the formation of limestone peaks and mountain chains of considerable extent. One of these lines of disturbances was along the supposed Cretaceous backbone of Louisiana, and the various outcrops represent the partially buried peaks of this chain. He thought that the saline deposits were laid down in early Tertiary time, rather than in late Cretaceous time, as Hilgard had supposed.

1893. Otto Lerch, "A Preliminary Report upon the Hills of Louisiana South of the Vicksburg, Shreveport & Pacific Railroad," *Bull. Louisiana State Exp. Sta., Geol. and Agr.*, Part II, 1893. Describes Drake's saline and gives a list of all known or supposed Cretaceous outcrops.

1895–96. T. Wayland Vaughan, "The Stratigraphy of Northwestern Louisiana," *American Journal of Geology*, Vol. 15 (1895), pp. 205–29.

———, "A Brief Contribution to the Geology and Paleontology of Northwestern Louisiana," *U. S. Geol. Survey Bull. 142*, 1896. Vaughan concluded that no folding or faulting was represented in the north Louisiana Cretaceous outcrops; that they were butte-like masses, formed by erosion in the land interval which separated the deposits of the Cretaceous and Eocene, and has since been covered by the younger deposits.

1899. G. D. Harris and A. C. Veatch, "A Preliminary Report on the Geology of Louisiana," *Geol. Survey of Louisiana, Report for 1899*, Part V, 1900. This publication contains a wealth of information and the most complete description of the geology of Louisiana heretofore published. These writers were first to recognize the quaquaversal structure associated with the Cretaceous outcrops. They further pointed out that the folding occurred, in part at least, since the deposition of the Claiborne.

1902. G. D. Harris and A. C. Veatch, "A Report on the Geology of Louisiana," *Geol. Survey of Louisiana, Report of 1902*, Part VI, 1902. This report is divided into several special papers. The Tertiary geology of the Mississippi embayment is described by Harris. The salines of north Louisiana are described in great detail by Veatch, who gathered a mass of historical data concerning the salt production. He reviews the evidence in support of the quaquaversal structure of the domes, and gives an ideal section of Drake's salt dome. He suggests that at the beginning of the Eocene they were either islands in the Tertiary sea or were so slightly submerged that the veneer of deposits they received was readily eroded in the following period; also, that the movement began in Cretaceous time and continued intermittently to the present time.

1906. A. C. Veatch, "Underground Water Resources of Northern Louisiana and Southern Arkansas," *U. S. Geol. Survey Prof. Paper 46*, 1906. This paper contains an excellent summary of the geology of southern Arkansas and northern Louisiana. It reviews the geologic history of the salt domes as stated in the earlier publication. Veatch also suggests a volcanic origin of the domes.

1907. G. D. Harris, "Notes an the Geology of the Winnfield Sheet," *Geol. Survey of Louisiana, Report of 1907*, Bull. No. 5, 1907. Contains a detailed discussion of Winnfield Quarry, Cedar Creek, and Coochie Brake salt domes. An ideal section of Cedar Creek dome is given.

———, "Rock Salt," *Geol. Survey of Louisiana, Report of 1907*, Bull. No. 7, 1907. This comprehensive paper contains a brief résumé of all of the salt domes described in the earlier papers. The theories concerning the origin of the domes are reviewed and discussed.

1910. G. D. Harris, "Oil and Gas in Louisiana," *U. S. Geol. Survey Bull. 429*, 1910. Contains a résumé of salt-dome data and a discussion of the occurrence of oil and gas.

THE BAYOU BOUILLON SALT DOME, ST. MARTIN PARISH, LOUISIANA

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ABSTRACT

The Bayou Bouillon salt dome is located in the swamps northeast of Martinsville, Louisiana. Cap rock appears to occur at depths of 1,500 to 2,000 feet. The salt has a rather gentle slope on the east and north, but the west and south sides of the dome are unexplored. Small quantities of heavy black oil have been found in shallow sands.

LOCATION

The Bayou Bouillon salt dome is in St. Martin Parish, Louisiana, in Township 9 South, Ranges 8 and 9 East, 15 miles northeast of St. Martinville. Situated in the midst of the Atchafalaya swamps, Bayou Bouillon can only be reached by boat. The most convenient point of access is Atchafalaya, a station on the Baton Rouge branch of the Southern Pacific Railway. The intricate system of bayous, lakes, and rivers in the swamps makes it possible to barge machinery and supplies into the district very cheaply.

The drilling crews usually live on houseboats, for the only dry land is that on the natural levees along the rivers, and this is covered with water for several months of the year. Fishing, lumbering, and gathering moss are the main occupations of the inhabitants, who live in small houseboats or in houses on the high ridges along the waterways of the swamp.

HISTORY

Bayou Bouillon means "bubbling" or "boiling" bayou. As early as 1833 this boiling was noticed, and old maps show the location of the bayou as we know it today. The Spindletop discovery in January, 1901, called attention to the oil possibilities of the Gulf Coast region, and two swampers, George Knight and E. A. Davis of St. Martinville, who had spent many years taking timber out of the swamps, went to Bayou Bouillon and found that the bubbles would burn. With Robert Martin and others they immediately purchased several thousand acres of land in the vicinity.

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[1] Consulting Geologist.

In the year 1902 four wells were started at Bayou Bouillon. O. W. Heywood, of Heywood Brothers of Spindletop and Jennings,

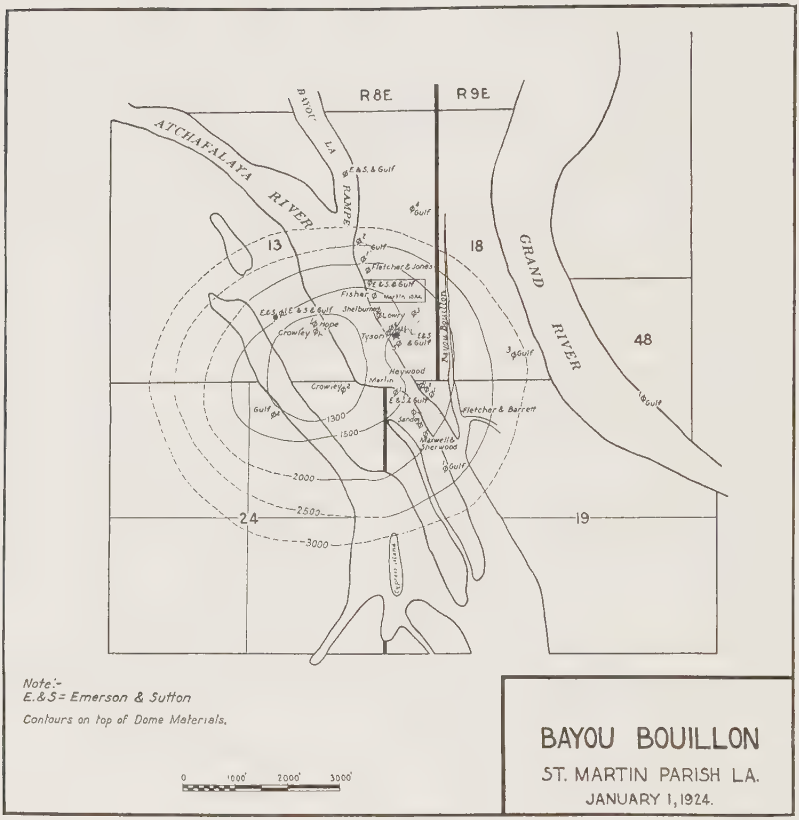

FIG. 1

F. F. Maxwell and W. D. Sherwood, Charles A. Lowry, and Shelbourne and Kelso were the operators. Heywood lost his first hole at 365 feet and then drilled a second test to a depth of 1,089 feet. All of these tests had showings of oil and gas, and it is said that some oil was bailed from the Heywood No. 2. By the summer of 1903 these tests had been abandoned. During the succeeding years a few holes were put down, the most important being the Crowley Oil and Mineral Company No. 2, which struck salt at about 1,650 feet.

In 1916 Sloan Emerson and Jim Sutton, who had been successful at Vinton and Edgerley, obtained leases and interested the Gulf Refining Company of Louisiana. Nine tests were drilled. One shallow well made about 25 barrels of oil per day and furnished fuel for operations for a period of two or three months. The Gulf Refining Company on its own account drilled No. 1 Prohaska on the east side of the Grand River in Iberville Parish.

In 1919, after the Gulf Refining Company had withdrawn, Emerson and Sutton drilled a 449-foot well which made about 10 barrels of oil per day.

In 1921 the Gulf Refining Company started drilling again and put down six tests. In 1923 the Gulf surrendered its leases.

In February, 1924, most of the land around the dome was purchased in fee by the Rycade Oil Corporation.

PREVIOUS REPORTS

Fenneman[1] and Harris[2] have published brief descriptions of Bayou Bouillon. Both of these authors state that 300 feet of limestone was reported in the Maxwell and Sherwood well between the depths of 850 and 1,150 feet, while the log of the well, as published, shows only 20 feet of "lime" from 830 to 850. However, this may be a typographical error, for Robert Martin, of St. Martinville, has a log in his office which shows "lime" from 850 to 1,150 feet. That this "lime" is cap rock is questionable, for sand is reported beneath it and subsequent drilling seems to indicate that the cap rock is between 1,500 and 2,000 feet in depth where this well was put down. In various papers Lee Hager, William Kennedy, Sidney Powers, and Alexander Deussen have mentioned Bayou Bouillon as one of the Gulf Coast salt domes.

PHYSIOGRAPHY

As has been noted, Bayou Bouillon is in the Atchafalaya swamps. No topographic mound is present. "Ridges" run through the swamps and along the banks of the rivers but these are probably

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[1] N. M. Fenneman, "Oil Fields of the Texas-Louisiana Gulf Coastal Plain," *Bull. U. S. Geol. Survey No. 282* (1906), p. 112.

[2] G. D. Harris, "Oil and Gas in Louisiana, etc.," *Bull. U. S. Geol. Survey No. 429* (1910), pp. 13 and 41.

BAYOU BOUILLON, ST. MARTIN PARISH, LOUISIANA, WELL DATA

Operator	Lease	Well Number	Date Completed	Total Depth (Feet)	Remarks
Crowley Oil & Mineral Co.....	Sec. 13	1	4/12/12	1,264	
Crowley Oil & Mineral Co.....	Sec. 24	2	7/31/14	1,866	Salt at 1,650?
Emerson & Sutton...........	Hope Oil Co. (Sec. 13, west of the river)	1	2/18/19	449	Made 10 bbls. of oil from sand at 437 to 449
Emerson & Sutton and Gulf Refining Co. of Louisiana......	Hope Oil Co. (Sec. 19)	1	5/26/16	1,360	Cavity at 1,360; lost log
Emerson & Sutton and Gulf Refining Co. of Louisiana......	Hope Oil Co. (Sec. 13, on east side of river)	2	9/10/16	1,740	1,674–1,740, black and white rock and lots of gypsum
Emerson & Sutton and Gulf Refining Co. of Louisiana......	Hope Oil Co. (Sec. 13, on east side of river)	2½	10/25/16	435	Produced about 25 bbls. of oil per day from sand at 412–435
Emerson & Sutton and Gulf Refining Co. of Louisiana......	Hope Oil Co. (Sec. 13, on east side of river)	3	1/10/17	1,620	1,550–1,620, black and white rock and lots of gypsum
Emerson & Sutton and Gulf Refining Co. of Louisiana......	Hope Oil Co. (Sec. 13, on east side of river)	4	1/17/17	650	Salt water
Emerson & Sutton and Gulf Refining Co. of Louisiana......	Hope Oil Co. (Sec. 13, on east side of river)	5	3/15/17	470	Salt water
Emerson & Sutton and Gulf Refining Co. of Louisiana......	Crowley-Martin 10 acres (Sec. 13)	1	6/10/17	1,847	1,700–1,786, hard sand and lignite (1,700–1,710, tested; blowout); 1,786–1,812, gumbo and gypsum; 1812–20, gypsum and broken rock; 1820–28, black shale, hard sand, oil; 1828–47, hard, porous, black rock

Emerson & Sutton and Gulf Refining Co. of Louisiana......	State land (Bayou La Rampe)	1	1/11/18	3,000	No dome materials
Emerson & Sutton and Gulf Refining Co. of Louisiana......	Atchafalaya Oil & Mineral Co. (Sec. 13, west of river)	1	3/31/18	1,615	1,500–1,510, gypsum and bowlders; 1510–1615, black and white rock with gypsum; located on Starvation Ridge, known as well No. 6
Fisher......................	Martin 10 acres (Sec. 13)	1	....	330	
Fletcher & Jones.............	Sec. 13	1	1903	....	Shallow test
Fletcher & Barrett...........	Sec. 19	1	1904	....	Shallow test
Gulf Refining Co. of Louisiana..	Prohaska (Sec. 48)	1	7/29/17	2,940	No dome materials
Gulf Refining Co. of Louisiana..	Hope Oil Co. (Sec. 13)	1	5/17/21	2,063	Cap rock 2,035–63; tested for oil at 2,031
Gulf Refining Co. of Louisiana..	Hope Oil Co. (Sec. 13)	2	8/25/21	2,690	Tested for oil at 2,499–2521; blue and black lime, 2,587–2,622; salt at 2622–90
Gulf Refining Co. of Louisiana..	Hope Oil Co. (Sec. 18)	3	1/24/23	3,000	2,401–74, hard sand and lime; 2,474–2,800, hard white sand; streaks of gypsum 2,800–2,852, sand and salt; 2,852–3,000, salt
Gulf Refining Co. of Louisiana..	Hope Oil Co. (Sec. 13)	4	7/10/23	3,560	Tested at 2,360 and 3,165
Gulf Refining Co. of Louisiana..	Atchafalaya Oil & Mineral Co. (Sec. 19)	1	2/9/22	1,895	1,679–84, shale and lime; 1,684–1,895, sand and lime
Gulf Refining Co. of Louisiana..	Atchafalaya Oil & Mineral Co. (Sec. 24)	2	10/15/23	1,377	1,324–26, gypsum rock; 1,326–32, black and white rock; lost returns; 1,332–77, sand rock and gypsum; lost returns
Heywood Brothers..........	Sec. 19	1	1902	365	See *U. S. Geol. Survey Bull. 429*, p. 41

BAYOU BOUILLON, ST. MARTIN PARISH, LOUISIANA, WELL DATA—*Continued*

Operator	Lease	Well Number	Date Completed	Total Depth (Feet)	Remarks
Heywood Brothers	Sec. 19	2	1903	1,089	See *U. S. Geol. Survey Bull. 429*, p. 41. Robert Martin attempted to deepen this hole but was unsuccessful, so he moved his rig a short distance and drilled the "Grant well"
Hope Oil Co.	Sec. 13	1	1908?	1,166	
C. A. Lowry	Sec. 13	1	1903	1,400	
Martin *et al*	Sec. 19	1	1908	1,800	"Black hot salt water." Located near Heywood wells, known as Grant well
Maxwell & Sherwood	Sec. 19	1	1903	1,555? 1,562? 1,158? 1,795?	See *U. S. Geol. Survey Bull. 282*, p. 113, and *Bull. 429*, p. 41, for log
Sandoz	Sec. 19	1	1908	1,600	Known as Eberhardt well
Shelbourne	Sec. 13	1	1902	810	See *U. S. Geol. Survey Bull. 429*, p. 41, and *Bull. 282*, p. 113, for log
Tyson	Sec. 13	1	11/5/15	290	

the result of the deposition of silt from the flood waters of the Mississippi which find their way into the Atchafalaya and thence to the Gulf of Mexico.

GEOLOGY

Along the banks and in the bed of the Bayou Bouillon there are gas escapes and beds of "paraffin dirt." Fenneman[1] evidently refers to "paraffin dirt" when he mentions the "occasional occurrences of an oily or asphaltic matter in the soil."

The extent and shape of the cap rock and salt are not known on the west and south sides of the dome. The information concerning many of the wells drilled is meager or entirely wanting.

The dome is probably cone shaped. On the east and north sides, as far as revealed, the flanks of the salt have, for a salt dome, a gentle slope. The thickness of the cap rock on top of the salt is not known, but it is probably 250 or 300 feet.

There is no log available of the Crowley No. 2 well, the only test which went through the cap rock on top of the dome and into the salt. Gulf Refining Company of Louisiana No. 2 Atchafalaya Land and Mineral Company found porous cap rock at 1,324 feet, the shallowest of which a record can be found. Gulf Refining Company No. 2 Hope Oil Company reports 35 feet of "blue and black lime" from 2,587 to 2,622 feet, and salt from 2,622 to the bottom of the hole at 2,690. Gulf Refining Company No. 3 Hope Oil Company reports salt at 2,852, but no cap rock overlying the salt.

OIL AND GAS

Only small amounts of heavy black oil have been produced at Bayou Bouillon from shallow wells. Nearly all the wells drilled report sands showing oil.

The possibilities of this dome as a producer of oil are by no means exhausted. The west and south flanks of the salt core have never been explored.

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[1] *Op. cit.*, p. 112.

SECTION 28 SALT DOME, ST. MARTIN PARISH LOUISIANA

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Houston, Texas

ABSTRACT

Gas and "paraffin dirt" prompted drilling of a test well northeast of St. Martinville, Louisiana. A showing of oil was found at a depth of 900 feet, and salt from 1,250 to 2,500 feet. There was no cap rock.

The Section 28 salt dome is in St. Martin Parish, Louisiana, 8 miles northeast of St. Martinville, in Township 9 South, Range 7 East, and in the western part of the Atchafalaya swamps. This locality has been called Catahoula Lake, Parks, and the Hager-Martin dome. A more appropriate name would be Bayou Martin, but as those who are interested in the locality commonly refer to it as Section 28, this name has been adopted for this paper.

In the year 1916 Lee Hager and W. C. Moore published a pamphlet entitled *Indications of Oil in the Gulf Coast Country*, which had wide circulation and aroused much interest in the search for new domes. As a result, Derneville Barras, of St. Martinville, found gas, and later Lee Hager found "paraffin dirt," near the southwest corner of Section 28, at the spot where the Hager well was later drilled. Robert Martin and his associates purchased lands around the prospect and made arrangements with Lee Hager and E. F. Simms to drill a well. The location was accessible only during periods of high water, so the derrick was built on piles 8 or 10 feet above the swamp level, and drilling started in May, 1917, and was completed in June, 1918.

A showing of oil was found at a depth of about 900 feet. No cap rock was encountered, but salt was found at 1,250 feet and continued to the bottom of the hole at 2,500 feet.

Deussen[1] gives the following information concerning material from this test:

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[1] Alexander Deussen, *Bull. Amer. Assoc. Pet. Geol.*, Vol. II (1918), p. 22.

A somewhat unusual find in this well was a sample of pinkish siliceous rock at a depth of 1,220 feet. Analysis showed a trace of sulphate of lime and about 35 per cent of carbonate of lime. It resembled volcanic ash, but Dr. Udden, to whom a sample was submitted, reported no ash present. The rock consists mostly of fine quartz grains with some zircon fragments. Somewhat similar deposits are encountered in the outcrop of the Fayette sandstones of Texas and west Louisiana some 100 miles to the northwest, and they also occur in the Catahoula formation which outcrops about 90 miles to the north. If a part of this formation, the normal position of these beds would be considerably deeper than found in this well, so that the evidence of uplift is unmistakable.

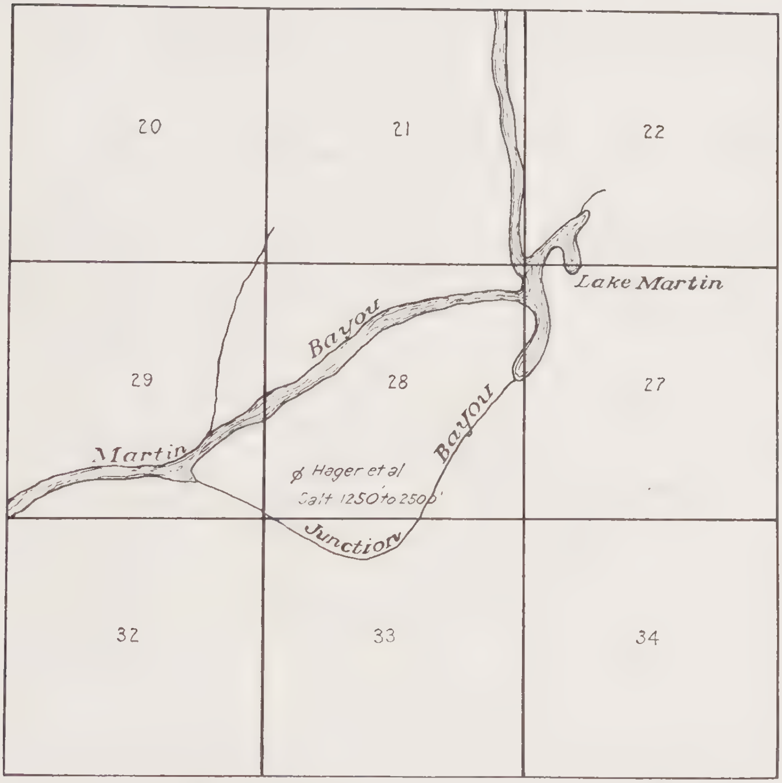

FIG. 1.—Section 28 Salt Dome, T. 9 S. R. 7 E., St. Martin Parish, La.

Since the completion of the Hager well the levee system has been extended, drainage canals are now being excavated, and preparations are being made for the building of a road to the dome from the state highway between Isle Labbe and Catahoula Lake. "Paraffin dirt" and gas have recently been found at other points near the Hager well. It is possible that these indications will be found all around the edge of the salt mass.

LOG OF WELL[1]

Formation	Depth (Feet)
Blue gumbo	83
Blue shale	103
Water sand	124
Sand shale	145
Blue shale	165
Shale bowlders	186
Sand	208
Shale	228
Gumbo	239
Sand gravel	274
Cemented sand gravel	301
Gumbo	313
Hard gravel	324
Lime rock	328
Gumbo	335
Shale	340
Lime shell	341
Gumbo	366
Hard blue shale	396
Gumbo bowlders	403
Gumbo bowlders	406
Sand blue shale	429
Sand gravel	451
Sand gravel	492
Rock pyrites lime	497
Sand	508
Gumbo	517
Gravel	520
Gumbo	570
Lime rock	585
Shale bowlders	628
Rock cemented sand set 10″	640
Cemented sand, very hard in streaks	710

[1] Drilled by Lee Hager, E. F. Simms, *et al.*, on Section 28 Salt Dome, St. Martin Parish, Louisiana. Drilling started May, 1917; drilling completed June 1, 1918.

Formation	Depth (Feet)
Cemented sand and gravel Barrels of nearly pure lime Thin streak of black shale Running Hughes bit last 5 feet	804
No report	951
Gyp rock with breaks of shale	1,030
Crystalized sand; contained water	1,085
Crystalized sand; breaks of gyp	1,136
Crystalized sand, gyp, hard rock	1,155
Packed sand and bowlders	1,167
Rock	1,171
Gypsum	1,186
Rock	1,190
Packed sand	1,193
Rock	1,205
Packed sand	1,209
Rock	1,214
Hard sand	1,227
Dark grey sand	1,235
Pink sand, very salty	1,250
Broken salt and sand	1,277
Salt rock	2,500

THE FIVE ISLANDS, LOUISIANA

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ABSTRACT

The Five Islands, so called, are in reality large, symmetrical hills, or rounded eminences, rising to an elevation of 100 feet or more from a flat, marshy plain in southwestern Louisiana. They are distributed at irregular intervals along a straight line which runs about northwest. They have aroused interest and published comment from scientists for more than a hundred years, and for a long time it has been generally known that these hills are underlain by immense bodies of salt and are the surface expression of recent upthrusting of salt plugs. Each of the islands is described in detail as to its geology, its record as a source of salt (several of the Islands have for years been the site of extensive salt-mining), and its possibilities for oil production. The evidence which these occurrences affords as to the origin of salt domes is analyzed. An extensive Bibliography is appended.

INTRODUCTION

The Five Islands are in reality five elevations along a line bearing S. 49° E. and running from Lake Peigneur, 10 miles west of New Iberia, to the mouth of Atchafalaya River. The lower four are either entirely surrounded by sea marsh or partly by marsh and partly by the water of embayments from the Gulf of Mexico. In order, from the northwest, they are: Jefferson Island, Avery Island, Weeks Island, Côte Blanche, and Belle Isle (Fig. 1).

Great masses of salt have been found beneath each of the islands, but only one, Belle Isle, has yielded even a trace of oil, and even here only small quantities have been found.

The islands attracted the attention of the earliest explorers in this part of the country, and numerous papers have been written concerning them (see appended Bibliography). Most of the early writings are of little scientific importance, as the descriptions were influenced by the theories of their origin advanced by the various writers, theories quite absurd in the light of present knowledge.

The papers by A. C. Veatch on "The Five Islands,"[50]* by G. D. Harris on the "Rock Salt in Louisiana"[51] and "Oil and Gas in Louisi-

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*Numbers refer to papers in Bibliography.

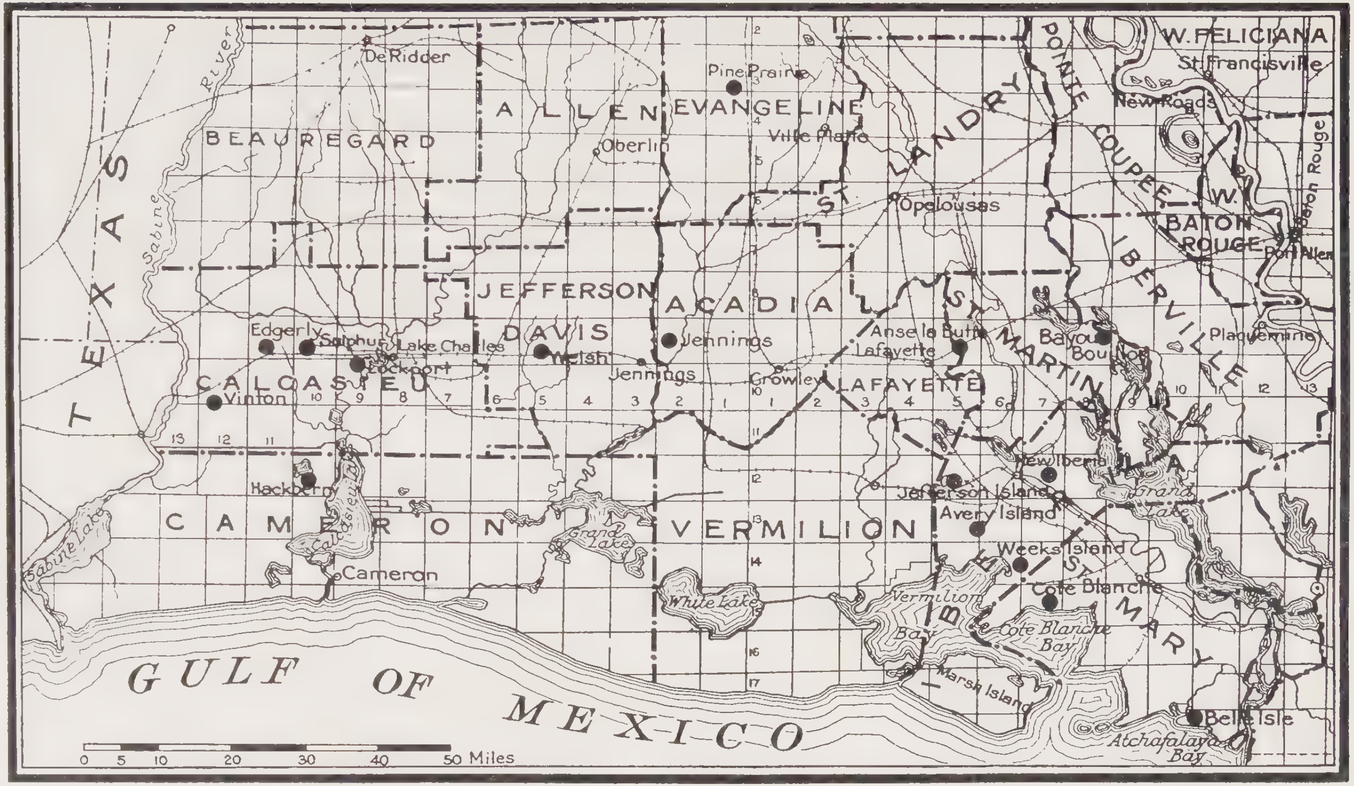


Fig. 1.—Map showing Salt Domes in southern Louisiana

ana,"[52] by Captain A. F. Lucas on "Belle Isle,"[54] and by G. S. Rogers on the "Intrusive Origin of the Gulf Coast Salt Domes"[55] are much better than the earlier papers and have been drawn on freely in the writing of the present paper. Material has also been received from numerous other sources, including companies and individuals who have been in close touch with the exploration and exploitation of the islands. For their kind assistance special thanks are due C. J. Webre, David Donoghue, T. W. Moore, Wallace E. Pratt, of the Humble Oil and Refining Company, Donald C. Barton, of the Rycade Oil Company, Sidney Bradford, of the Avery Rock Salt Mining Company, and H. C. Fultz, of the Myles Salt Company, Ltd.

JEFFERSON ISLAND

LOCATION

Jefferson Island is on the southeast side of Lake Peigneur about 9 miles west of New Iberia, and may easily be reached from there by automobile. It is only a short distance north of Bob Acres, a station on the Abbeville branch of the Southern Pacific Railroad, which leaves the main line at New Iberia.

HISTORY

For many years this island was best known as "Côte Carline," which name was used as early as 1818 by Darby in his *Emigrant's Guide to the Western and Southwestern States*.[3] Later it was variously called Depuy's Island, Miller's Island, and Orange Island. The present name is after Joseph Jefferson, the actor, who for many years had a winter home there.

In 1894 Mr. Jefferson let a contract for drilling a well near his home, and this resulted, early in the summer of 1895, in the discovery of salt at a depth 334 feet. Three years later, eight holes were drilled to determine the form and extent of the salt mass. Only four reached the salt, and the work was discontinued.

In July, 1919, C. J. Webre, under the management of Lawrence Jones and J. L. Bayless, of Louisville, Kentucky, drilled thirty-six holes and contoured the salt (Fig. 2). In October of the same year, these gentlemen organized the Jefferson Island Salt Mining Company and began sinking a shaft, which, however, was lost at the top of the salt. During the month of March, in the following year, another shaft was started, but owing to difficulties in sealing off the water, it was not completed until February, 1922. Some time was required to cut out a working space of sufficient size to permit operations on the scale contemplated by the management, and regular production was not under way until April, 1923. Since then production has been continuous.

PHYSIOGRAPHY

In reality Jefferson Island is not an island, since it rises from a nearly dry plain, but it is called an island because of its general resemblance to the other members of the Five Island group. The area of the island is about 300 acres. It rises to a maximum elevation of

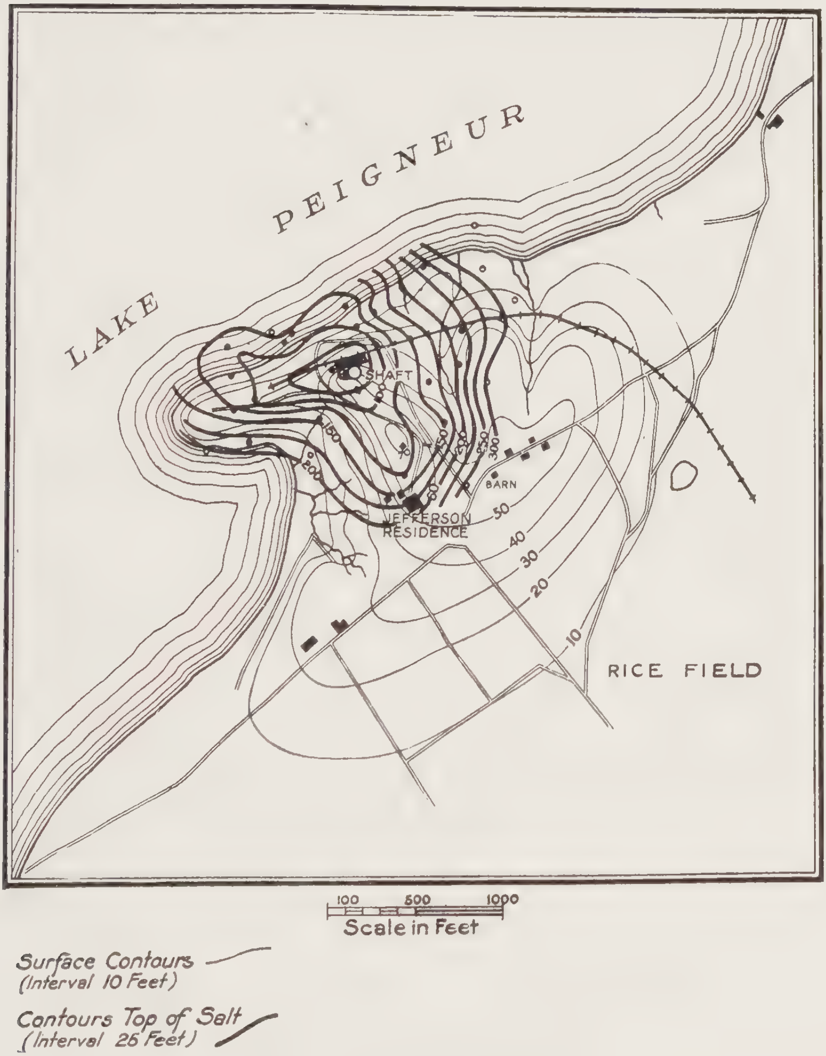


FIG. 2.—Map of Jefferson Island

75 feet above the plains and is of rather smooth contour, with the exception of a wave-formed bluff, 30 feet in height, which faces Lake Peigneur to the north. This lake is about 2 miles long, and its depth is variously estimated from 15 to 30 feet. The plains surrounding the island are low, and since they are easily flooded, they are used for the cultivation of rice.

GEOLOGY

Surface.—In the bluff on the north side of the island the section shown in Table I is exposed.[51] This is the only place on the island where gravel is exposed, clay and surface soil being found elsewhere.

TABLE I

Section on North Side of Jefferson Island

	Feet
Surface soil, yellow clay darkened by organic matter....	2
Light yellow clay with limestone concretions...........	26
Gravel..	2

Subsurface.—In the course of operations in connection with the exploitation of the salt stock, it was found that the overlying strata are predominately sand and gravel, with less important beds of blue clay. All are so lenticular as to mask any arching due to the upthrust of the salt. Cap rock was found in only a few holes and consists of 18 to 24 inches of porous gray limestone. Three holes failed to encounter salt, although drilled somewhat deeper than those that did, the deepest reaching a depth of 475 feet below sea-level. The strata penetrated are essentially of the same character as those overlying the salt.

Through the exploration work by drilling, carried on during the year 1919, the form of the uppermost part of the salt stock was determined to be as shown on the accompanying map. Judging from the general contour of the portion which has been mapped, it seems that the salt core probably extends some distance beneath the lake to the north.

PALEONTOLOGY

A number of fossils were found in the railroad cut on the north slope of the island, and these have been identified by W. C. Mansfield, of the U. S. Geological Survey, and W. B. Marshall, of the U. S. National Museum, as follows:

Vivipara subpurpurea Say?
Pleurocora near *P. filum* Lea

Quadrula pustulata Lea
Crenodonta hers (Say) Ortmann
Amygdalonsaias elegens (Lea) Ortmann
Rangea cuneta Gray
Erynia parva (Barnes) Ortmann
Unionidae, fragments

Of their age Mansfield says, "All the molluscan specific names of genera are represented in the Recent fauna. The horizon, as indicated by the imperfect preservation of the fauna, probably is late Pleistocene or early Recent." As these could not have been deposited in their present position, they indicate that the mound was probably formed by a very late Pleistocene or post-Pleistocene uplift.

SALT PRODUCTION

The shaft enters the salt stock almost at its highest point, which is about 40 feet below sea-level and 100 feet below the surface of the ground. The shaft, which is circular in form, with an internal diameter of 25 feet, is walled with concrete and reaches a depth of about 900 feet. It is divided into four compartments, and the salt is hoisted by an Allis-Chalmers balanced hoist with skips of 5 tons capacity.

Mining is carried on by an adaption of the shrinkage system. A large undercut is made by drilling and blasting, the salt being loaded into cars by hand shoveling. Then slice after slice is blasted down, the fallen salt serving as a working floor, until the desired height is reached. In this manner large chambers 40 feet wide by 80 feet high are cut. The broken salt is loaded into cars by large electric shovels and then hauled to the shaft.

The salt from the different stocks of the Five Island group varies somewhat in physical character. That at Jefferson Island is particularly firm and shows very little tendency to shatter when struck with a hammer. It is also rather free of impurities and is on the whole of lighter color than the salt from the other islands.

AVERY ISLAND

LOCATION

Avery Island is about 10 miles southwest of New Iberia and 3 miles from the shores of Vermilion Bay. It was originally isolated by the surrounding marshes. However, as early as 1818 a raised dirt road or causeway had been built from the northernmost point of the island to the mainland.[3] Communication by water was greatly hindered by a bar at the mouth of Petite Anse Bayou. This was partially overcome in 1880 by digging a canal from the lower part of the bayou across the marshes to the Gulf. In 1886 a branch of the Southern Pacific was completed from New Iberia to the island.

HISTORY

This island was until recently best known as Petite Anse. Earlier names used were Thomas' Island, Marsh's Island, and Salt Island.[4]

That the existence of brine springs here was known to the aboriginal inhabitants long before the coming of white men is shown by a great deposit of potsherds and ashes, extending over an area of approximately 5 acres and in places nearly 3 feet thick. However, this work was long abandoned, and the Indians found by the whites knew nothing of the springs.

The springs were rediscovered in 1791 by one John Hayes while hunting, and an attempt was soon made to use the water for the recovery of salt.[50] In 1812, due to the demand and increased value of salt resulting from the war, John C. Marsh, owner of the island, established quite an industry and by 1817 was supplying to a large extent the demands of the settlements of Attakapas and Opelousas.[3] However, the competition of imported salt eventually crushed the local industry, and operations ceased.

Following the opening of the Civil War, salt became very scarce, and John Marsh Avery, the eighteen-year-old son of Judge D. D. Avery, owner of the island, and grandson of John C. Marsh, who built the old salt works in 1912, reestablished the industry. The demand soon overtaxed the capacity of the springs, and it was decided that the salt wells be cleared and deepened. In the course of this work massive rock salt was found, which subsequently proved to be part of a great stock underlying the island. The date of this discovery was May 6, 1862. For nearly a year following, salt was quarried from a number of large open pits,[6-9] but on April 17, 1863, this activity was brought to an end by the destruction of the works by the Federal forces under General Banks.[8] The amount of salt taken out during this period is variously estimated between 10,000 and 30,000 tons.

No further work was done until 1867, when Chouteau and Price sunk the first shaft, 8 by 8 feet in plan, and 83 feet deep, afterward increased to 90 feet, about 58 feet being in solid salt. Galleries 8 to 10 feet high and 25 feet wide were driven east and west. In 1870 Mr. Price died and Mr. Chouteau abandoned the mine.

In 1879 the mining rights were leased to the Galveston Company, and in 1880 they were transferred to the American Salt Company, which occupied Chouteau's 90-foot shaft and fitted up a mill for crushing the salt. The salt was mined by cutting chambers and cross-headings averaging about 40 feet wide and 25 or more feet high, pillars 40 feet in diameter being left to support the roof.

To secure transportation, a canal was cut across the marshes from a point near the mouth of Petite Anse Bayou to the Gulf. A tramway was built from the mine, and a short embankment was made across the marsh to Petite Anse Bayou, where a number of slips were dug. The salt was loaded into lighters and carried down the bayou to Vermilion Bay, where it was transferred to schooners. This did not prove very satisfactory because of the cost of transfers and because the lighters and schooners frequently ran aground on the mud-flats and bars.

In 1886 the American Salt Company was succeeded by the New Iberia Salt Company, which made arrangements with the Southern Pacific Railroad for a branch line from New Iberia. This was completed in 1886 and solved the question of transportation.

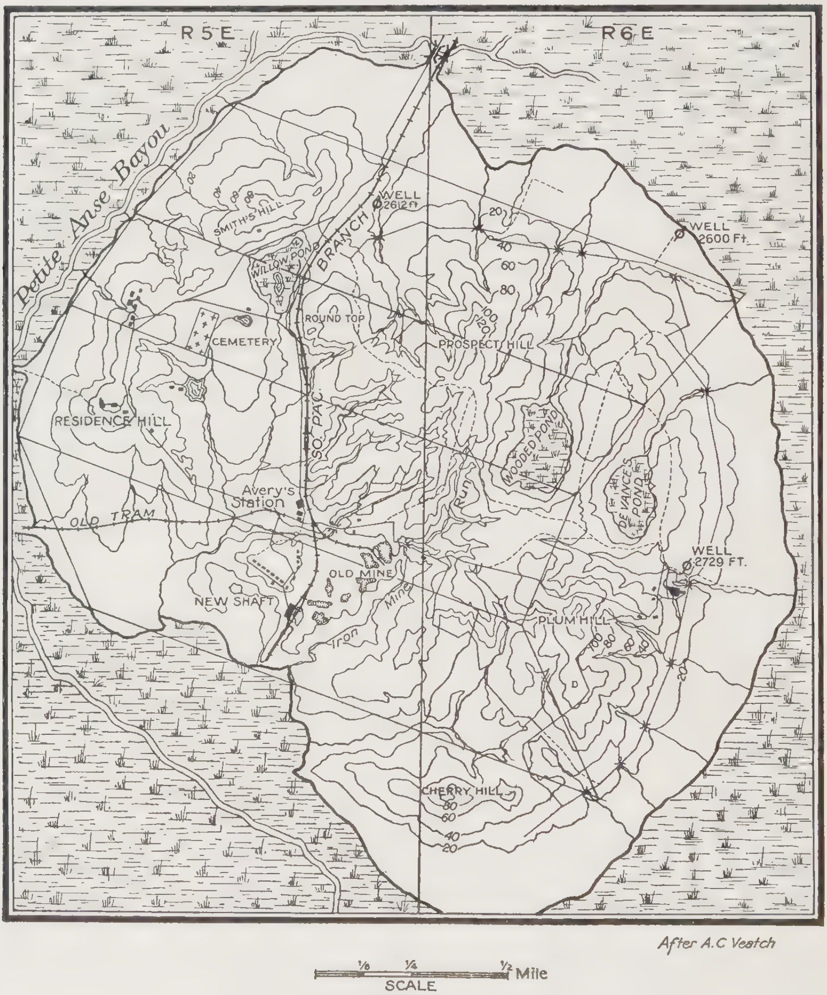
The extreme irregularity of the surface of the salt was not fully appreciated by the companies first engaged in its mining. The galleries on the 90-foot level were driven under the false belief that there was a thickness of 40 or 50 feet of salt above them, and they soon approached the outer limit of the salt. Water commenced to come into the mine through the crevices and, once started, but little time was required for it to dissolve the salt and form larger holes. Thus the first sink hole was formed as early as 1883. Others soon developed, and the sand, water, and débris carried into the mine greatly interferred with mining operations. First the eastern and then the western side of the mine was abandoned, and finally (1885) it was decided that the shaft be sunk 70 feet deeper. This additional depth, with the 8 feet required for the pump, made the total depth of the working shaft 168 feet. Work was prosecuted on the 160-foot level by driving galleries and crossways 80 feet wide and 40 feet high and leaving supporting pillars 60 feet in diameter.

On July 1, 1893, Myles and Company, of New Orleans, obtained a sublease on the property. The water which entered the upper levels through the sink holes finally effected an entrance to the lower levels and caused that part of the mine to be abandoned in July, 1895. Operations were continued in the upper level till 1896, when the mines reverted to the Avery family by default of contract.

In 1898 the Avery Rock Salt Mining Company was organized to carry on operations in the old mine and to sink a new shaft. Borings were made and a site was selected southwest of the old mine and beyond the limits of the old workings. After considerable trouble with water-bearing sands and gravels, the salt stock was entered at a depth of 54 feet. Profiting by the history of trouble with water breaking in, the new management sunk the shaft to a depth of 518 feet, thus getting well within the salt body. The shaft was completed in 1899 and is still in use. In the summer of 1922 a second shaft was sunk for ventilation.

PHYSIOGRAPHY

Avery Island is roughly oval in form, its greatest diameter, of about 1½ miles, trending in a northwesterly direction. It is almost entirely surrounded by marsh land. On the east and southeast there is a large cypress swamp. The western side is skirted by Petite Anse Bayou, branches of which run along the northern and southern sides and finally lose themselves in the marsh (Fig. 3).



After A.C Veatch

FIG. 3.—Map of Avery Island

The maximum height is 152 feet above the marshes. The surface is extremely uneven. Several large ponds are present, some of which appear to be sink holes, probably formed by the removal of salt from beneath by solution; indeed, it may be that the general rough character of the topography is due in a large part to the same action.

GEOLOGY

Surface.—Even before any considerable work by man, Avery Island presented more exposures of the materials underlying the surface than the other members of the group; with railroad cuts and the development of sink holes from mining operations, considerably more is exposed.

While the island is mostly covered with a brownish-yellow loam, there are in the southern part numerous exposures of gravel. These are best seen on Cherry Hill and at the shaft. Sand and gravel from pits along the railroad track are used for ballast along a considerable portion of the Southern Pacific line. While this sand is of fairly good quality, the best is obtained near the mouths of the ravines, where the little clay contained has been removed by water.

Sandstone outcrops along the sides of the ravine known as Iron Mine Run from the old salt mine almost to its head, where several small gullies branch off, and thence along a line running northeastward, almost to Willow Pond. As exposed, it is a fine-grained pink sandstone with scattered particles of hematite, but underground it is chocolate colored and in places it is rather coarse. The large sinkhole near the old mine extends 63 feet below the surface and affords an excellent exposure. The sediments here are almost entirely white and orange sands, with occasionally some gravel and masses of clayey sand. The true dip of the series is marked by cross-bedding, false-bedding, and landslides.

In the northern part of the island there are numerous outcrops of a variegated chocolate, yellow, and green jointed clay, the most notable occurring on the northwest slope of Prospect Hill, on the western slope of Smith's Hill, in the railroad cut northeast of Avery's Station, and on both the eastern and western slopes of Residence Hill. False-bedding and cross-bedding render dip determination practically impossible.

In one of the gullies at the head of Iron Mine Run there is exposed a bed of lignite. A shaft 30 feet deep was sunk in an attempt to mine this for local consumption, but the project was soon given up. The bed was found to be 18 feet thick, and it is underlain by at least 85 feet of clay, as is shown by a near-by boring. The beds dip 44° SE., and strike S.21° W. A boring 220 yards farther down the gully passed through the section shown in Table II.

The sediments in this section are stratigraphically higher than the lignite, and the absence of the latter from the section, together with its dip as mentioned above, shows clearly that it dips downward against the salt.

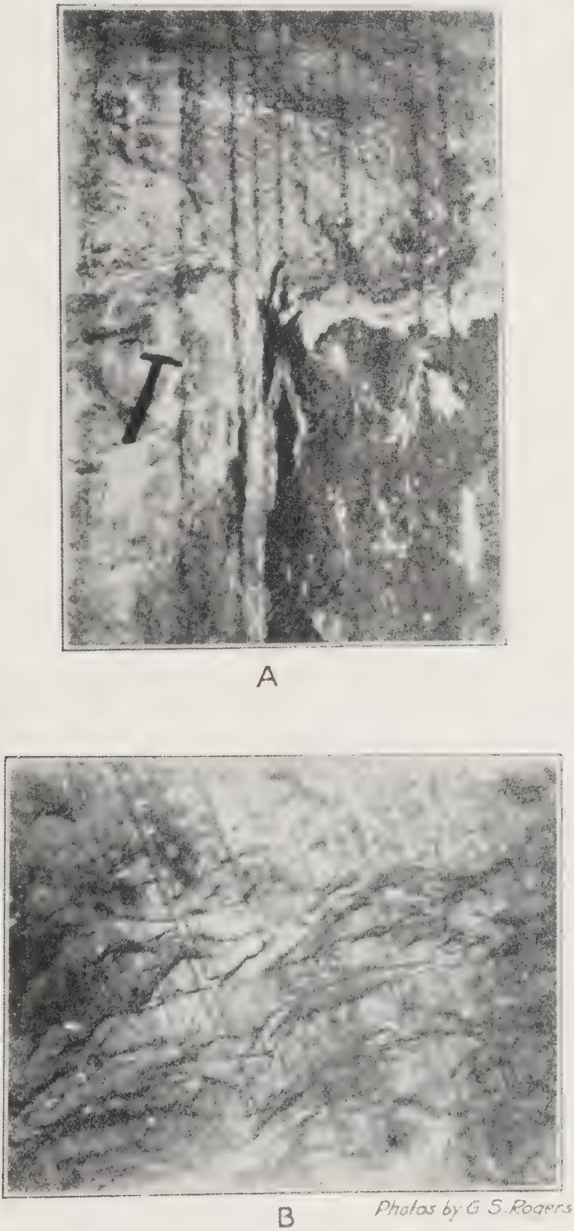
Subsurface.—The most important underground feature is the salt stock, which is overlain and surrounded by sedimentary strata. The areal extent of the stock has not been determined. A few drill holes were sunk in the vicinity of the mine to eliminate the possibility of extending the workings out of the salt, but none of these were off the edge of the stock. This proved a comparatively small area, but the salt is believed to underlie the greater part of the island, since it is well established that, in common with the other islands of the group, this island owes its origin to the upthrust of the stock. This stock is the highest in the Gulf Coast district, the uppermost part being a few feet above sea-level and only 17 feet below the surface. Due to unequal removal of salt by solution, it is extremely uneven, a change in elevation of 80 feet in less than 200 yards having been observed.

TABLE II

SECTION IN IRON MINE RUN, AVERY ISLAND

	Depth (Feet)	Thickness (Feet)
Fine, sandy clay soil	0–4	4
Very fine-grained, soft, pink, and drab or purple sandstone	4–160	156
Hard, coarse-grained, chocolate-colored sandstone	160–66	6
White rock salt, lower limit not reached	166–1,005	839

In a general way the salt mass resembles a schist, because of the streaked banding of light and dark salt (Figs. 4 and 5). In vertical section the streaks are seen as parallel bands, the dark being 2 to 6 inches wide, the light somewhat wider. In plan they are very irregular, twisting, folding, and forming all sorts of figures within the mass. However, near the outer margins they are more or less parallel to



Photos by G. S. Rogers

FIG. 4.—Flow Structure in the Salt, Avery Island, La.

the walls. These facts, together with the elongated forms commonly exhibited by the individual salt crystals, indicate that the salt has flowed vertically, and affords rather convincing evidence that salt domes are due to intrusions of great masses of salt which are plastic under pressure.

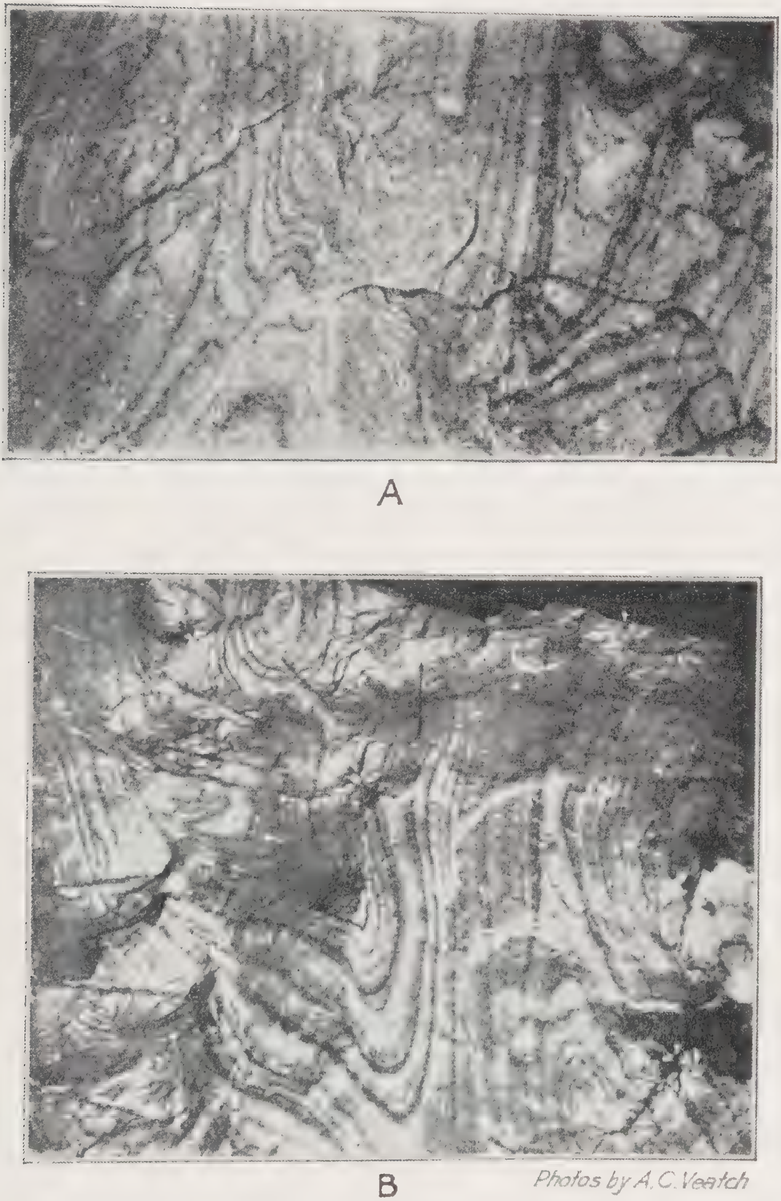
The salt is mostly white, hard, dry, and crystalline, the individual crystals varying from $\frac{1}{8}$ to $\frac{1}{4}$ inch across and up to more than 2 inches in length. The salt stands up well, and practically all can be shipped as rock salt, differing in this respect from the salt at Weeks Island, which shatters readily. The purity of the salt, even of the darker portions, is remarkable. These darker portions, so evident as streaks or bands, are not caused by any dark substance, but by the absorption of light rays by minute particles of transparent anhydrite. This anhydrite may easily be filtered from water in which dark salt has been dissolved. Analyses of light and dark salt are given for comparison (Table III).[51] Other analyses of salt from this dome are given in Table IV.[50]

TABLE III

ANALYSES OF LIGHT AND DARK SALT FROM AVERY ISLAND

	Light Salt	Dark Salt
NaCl	99.10	96.53
H_2O	0.10	0.20
$CaSO_4$ (soluble)	0.33	1.05
$CaSO_4$ (insoluble)	0.23	2.16
	99.75	99.94

The only foreign material found within the salt core is a rather thin mass of tough red sandstone which extends vertically at least 80 feet and along its strike a distance of 75 feet.[55] It is extremely irregular in thickness, ranging up to 10 inches in some places and pinching out in others. Though tough, the rock is brecciated, the many small fissures being filled with salt. Under the microscope it is seen to consist chiefly of quartz crystals with a few fairly fresh feldspars. Some of the grains are well rounded, but others are angular. Most of the quartz grains show evidence of strain, and there has been considerable secondary growth. The cement is chiefly silica and iron oxide.



Photos by A. C. Veatch

FIG. 5.—Flow Structure in the Salt, Avery Island, La.

The cement and secondary growth of the quartz grains indicate circulation of ferruginous and siliceous waters after the sand had become placed, and such waters could not have circulated through the salt mass without dissolving much salt and introducing much foreign material. The rock must therefore have been cemented before it entered the salt mass. Also, its irregularity in thickness and vertical attitude suggest that it has been stretched out under pressure. It therefore seems to represent a fragment of sandstone picked up by the salt in its upward course, and there appears to be no way of ascertaining the formation from which it was derived. In general appearance it does not resemble any Tertiary rock in this district, but its red color suggests that it is Permian, for similar rocks are commonly found in the Permian series of the Texas Panhandle. However, such a correlation must not be too readily accepted.

TABLE IV

ANALYSES OF SALT FROM AVERY ISLAND

Chemist	NaCl	$CaSO_4$	$CaCl_2$	Mg_2Cl	$MgSO_4$	Other Matter	Not Determined
Jules Lafort	97.92						2.08
E. W. Hilgard	99.88	0.126	trace				
Peter Colloer	98.90	0.838	0.146	0.022		0.080	0.014
Dr. Riddle	98.88	0.76	0.13	0.23			
C. A. Goessman	98.88	0.79	trace	trace		0.33	
C. A. Goessman	98.88	0.782	0.400	0.003		0.33	
Joseph Jones	99.617	0.318			0.062	0.003	
F. W. Taylor	98.71	1.192	trace	0.013		0.03	
Dr. Doremus	99.097	0.729			0.158	0.039	
Gustavus Bode	99.252	0.694	0.042	0.012			

All the fossils found on the island are of Quaternary age. Since all the sediments overlying the salt in the southern part of the island seem to belong to the same series of sands and gravels as those in which these fossils were found, it appears that they are all of Quaternary age. The section passed through by the present shaft is shown in Table V. The clays found in the northern part of the island are soft, and it is believed that they also are Quaternary because of their close association with the gravels and the lack of any decided break between them.

Normally, the beds overlying a salt stock are nearly flat or rather gently arched. It follows, then, that the attitude of the strata in Iron Mine Run, where they are seen to dip down against the salt, is certainly normal. This is very probably due to slumping resulting from the solution of the salt, and bears out the idea that the general rough topography of the island results from this sort of action.

TABLE V

SECTION OF SALT-MINE SHAFT, AVERY ISLAND

	Depth (Feet)	Thickness (Feet)
Surface soil	0–4	4
Yellow sand	4–16	12
Sandy clay and gravel (water line at 24 ft.)	16–24	8
Sand and gravel	24–54	30
Salt	54–	

Three wells throw some light on the character of the sediments around the salt core. The section penetrated by the well near Sugar House is given in Table VI. This well clearly marks the eastern margin of the salt, since it penetrates both salt and sediments.

TABLE VI

RECORD OF A WELL NEAR SUGAR HOUSE, AVERY ISLAND

	Depth (Feet)	Thickness (Feet)
Superficial detritus	0–330	330
Rock salt	330–2,593	2,263
Blue sand (some gas) (struck a log at 2,643 feet)	2,593–2,643	50
Blue gas sand	2,643–2,663	20
Salt	2,663–2,727	66
Bottom of hole still in salt	2,727–	

A deep well by the railroad track near the north end of the island passed through the section shown in Table VII.

Another well was drilled to a depth of 2,600 feet about $\frac{3}{4}$ mile east of the second, but nothing new was found in the section.

The sediments passed through by these three wells are similar in every particular, including the buried logs, to those now being laid down in this region, and accordingly are thought to be of Quaternary age. This conclusion is further justified by the fact that the wood, discovered at depths of 2,643 feet and 1,400 feet, is in a much better state of preservation than would be expected from any Tertiary lignite bed.

PALEONTOLOGY

Hilgard reports finding imperfect vegetable remains, shells of *Paludina*, and several species of *Unio* and a *Cyclas* on the eastern slope of Residence Hill. Of greater interest, however, are the vertebrate remains found in the sections exposed by the sink holes between the old and new mines, where bone and pottery beds are found.

The first notice of vertebrate remains on the island, according to Veatch, was given by Professor Joseph Henry in a paper before the Chicago Academy of Sciences, on the verbal statement of a Mr. T. F. Cleu, who contributed a specimen of basket work to the Smithsonian Institute.[21] Dr. Richard Owen, who visited the island in 1865, mentions the occurrence of pottery, but says nothing about fossil vertebrates. In 1883 Mr. William Crooks, of the American Salt Company, presented to the Smithsonian Insitute a collection of bones obtained while sinking an air shaft. These were studied by Professor Joseph Leidy, who made them the subject of a brief communication to the Philadelphia Academy of Sciences in 1884[28] and of a detailed report published in the *Transactions of the Wagner Free Institute of Science* in 1889.[34] In this he lists:

TABLE VII

RECORD OF WELL IN NORTH PART OF AVERY ISLAND

	Depth (Feet)	Thickness (Feet)
Yellowish clay	0–500	500
Gravel	500–700	200
Gray sand (water stratum at 1,000 feet)	700–1,000	300
30 feet of shells, approximately	1,000–1,100	100
Gray sand (logs passed through at 1,400 feet)	1,100–1,400	300
Gray sand	1,400–2,612	1,212

Mastodon americanus
Mylodon sp. cf. *robustus* Owen
Mylodon harlani Owen
Equus major De Kay

At about this time General Dudley A. Avery gave several bones to the Smithsonian Insitute, and one of them was identified as the claw of a *Megalonyx*.

Probably the largest collection from this locality is that made by Dr. Joseph F. Joor in 1890 for Tulane University.[39] These were studied by Professor E. D. Cope,[40] who described two new species of *Mylodon* and expressed the belief that the teeth identified by Leidy as *Equus major*, De Kay, really represented a new species. The species recognized by him are:

Mastodon sp.
Mylodon harlani Owen
Mylodon renidens Cope
Mylodon sulcidens Cope
Equus intermedius Cope

To this list Dr. Joor adds, with some doubt, the remains of an *Elephas*. The bone bed is rich and might yield some good material to the careful worker.

On the north side of one of the sink holes resulting from water entering the old mine, bones were found buried beneath about 17 feet of sediments. The section exposed is as shown in Table VIII. Formerly about 10 feet of salt was exposed in this section below the bone beds, but this is now hidden.

According to descriptions, a fairly complete skeleton of a mastodon was unearthed in grading for the railroad embankment just south of the shaft now in use, but it was buried in the course of the work before being seen by anyone appreciating its value. A few bones which rolled to the foot of the embankment were later picked up by General Avery, and a piece of tusk about three feet in length was found by a workman.

A few scattered bones have been found in Iron Mine Run a short distance above the old mine, but no determinations are available.

SALT PRODUCTION

The shaft now in operation enters the salt a few feet above sea-level. It is 21 by 10 feet, 518 feet deep, and is divided into three compartments, two being used for hoisting, the other for compressed air for power, electric wires, and ventilation. As at Jefferson Island, the salt is mined by undercutting, breaking down the salt, and loading into cars by electric shovels. It is then haluled to the shaft by an electric locomotive. Formerly, galleries 30 feet wide by 60 feet high were worked, leaving pillars 30 feet square. Other sizes have also been used. The galleries now being driven are from 40 to 60 feet wide and 60 feet high (Fig. 6).

Instead of using skips for hoisting the salt, the mine cars are run upon the cages and hoisted to the top floor of the mill, where they are dumped. The purity of the salt is such that no refining process is required. The salt is simply crushed, screened, ground, and winnowed to drive off the fine salt dust which has a tendency to deliquesce and cement together the larger grains.

TABLE VIII

SECTION IN SINK HOLE ON AVERY ISLAND

	Depth (Feet)	Thickness (Feet)
Gray sandy loam with pebbles	0–7	7
Broken pottery and ashes	7–8	1
Dark-gray silt	8–13.5	5.5
Fine black loam containing many grass roots	13.5–15	1.5
Medium-coarse white sand grading into gravel	15–17.5	2.5
Black to dark-brown, very hard, medium-fine gravel containing remains of vegetable matter, *Mastodon*, *Mylodon*, and *Equus* bones	17.5–19.5	2

The total production of salt from Avery Island up until January 1, 1924, was 2,578,379 tons, of which 1,866,163 tons were taken from the new shaft. The annual production for several years has been about 100,000 tons, that for 1923 having been 92,000 tons.

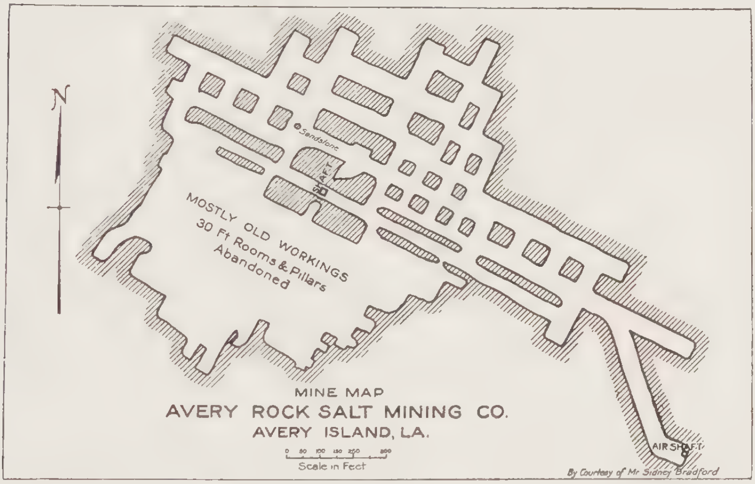
WEEKS ISLAND

LOCATION

Weeks Island is 15 miles south of New Iberia and is on the east side of Weeks Bay, an eastern lobe of Vermilion Bay. Before the Civil War it could be reached from the mainland only by canoe through Weeks Bayou from Prairie au Large below New Iberia. The products of the island, of which sugar was most important, were shipped by shallow-draft schooners which could enter the bay. During the war, or shortly afterward, a raised dirt-way was built to the mainland. A road is maintained over this, and the island may be reached easily by automobile from New Iberia. A short track from the Cypremort branch of the Southern Pacific, leaving the main line at Baldwin, also goes to the island.

HISTORY

Previous publications[50] on this island have called it Grand Côte, but as it is at the present time best known as Weeks Island, it is so called in the present writing.



By Courtesy of Mr Sidney Bradford

FIG. 6.—Mine Map, Avery Rock Salt Mining Co., Avery Island, La.

The discovery of salt on Avery Island in 1862, and the high price of salt at that time, caused a few wells to be dug in search for salt on Weeks Island, but without success. Following this failure no further work was done until after the discovery of salt on Jefferson Island in 1895 and on Belle Isle in 1896, when Mr. F. F. Myles undertook the exploration for salt in a more systematic way. In March, 1897, with Mr. N. Conrad in charge of the drilling, he started the first hole near the sugar house. Salt was struck in the fourth hole at a depth of 276 feet, July 25, 1897. About this time Captain A. F. Lucas, later of Spindletop fame, was put in charge. In all, fourteen holes were drilled in the preliminary examination, several of these running into the salt. In 1898 the Myles Salt Company was organized and fourteen additional holes were drilled to determine the best location to begin mining operations. A shaft was started in July, 1898, best location to begin mining operations. A shaft was started in July, 1898, over the highest point on the salt stock. One hundred feet of sectional cast-iron tubular casing 10 feet in diameter were used in sinking to the salt. Because of trouble with water, nearly three years were required to sink the shaft into the salt and make a perfect seal. A rectangular shaft was continued to a depth of 645 feet below the surface. Production began in March, 1902, and has been practically continuous up to the present time.

PHYSIOGRAPHY

Weeks Island is nearly circular in outline and is about 2 miles in diameter (Fig. 7). On the three sides away from the bay, which lies to the west, there is a great sea marsh. The island rises to a maximum height of 135 feet above sea-level, and the surface is very uneven, partly due to dissection and partly to slumping resulting from salt below being dissolved and carried off in solution; bonds and small lakes represent modified sink holes.

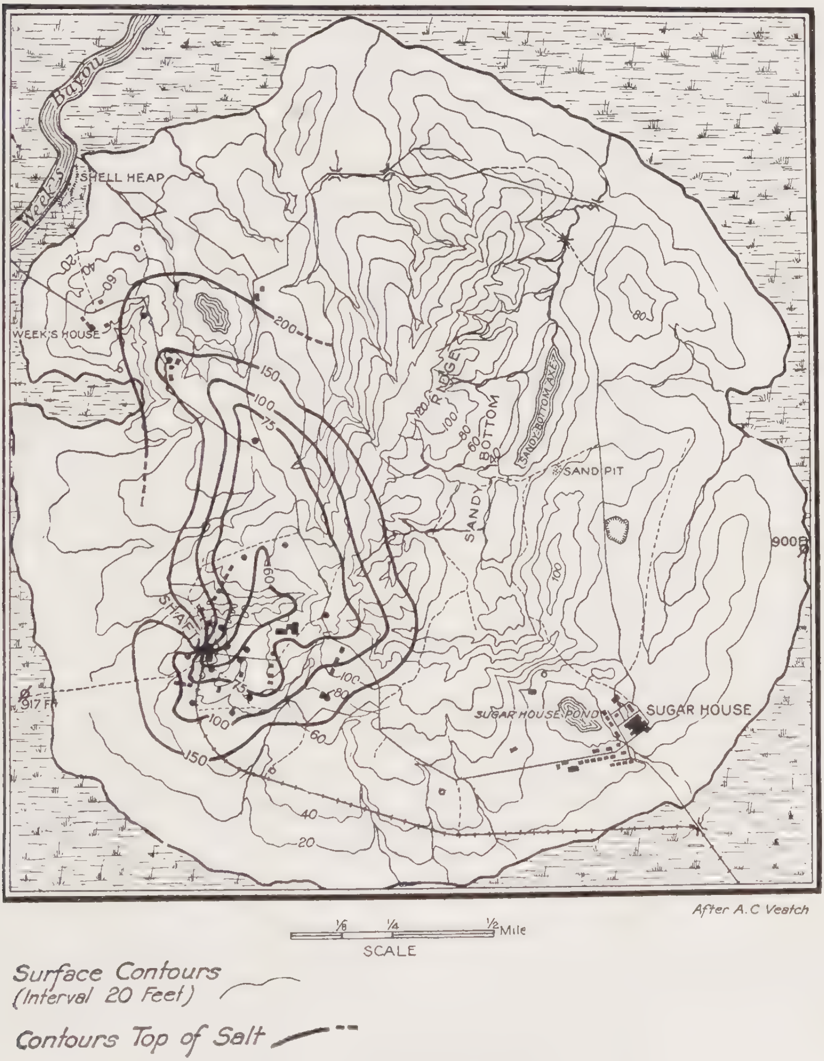
The Devil's Backbone, the principal topographic feature, occupies the central part of the island and has a general trend a little east of north. The slopes of the gullies on either side are almost vertical and from 20 to 60 feet in height.

GEOLOGY

Surface.—Nearly the whole of the island is covered with a brownish-yellow loam, but in places, notably in the sharp gullies on the east side of the Devil's Backbone, the upper stratum of clay has been cut through so as to expose underlying sands and gravels. Toward the southern part of the ridges there are ferruginous sands. These contain chert pebbles and an occasional interstratified bed of sandy gray clay. The whole mass has been so tilted that the planes of stratification dip in various directions and at different angles. Springs are common on the northern slopes of the island.

Subsurface.—The contour of the top of the portion of the salt stock underlying the western part of the island has been determined by drill holes and is shown in Figure 7. The portion in the vicinity of the shaft is shown in more detail in Figure 8. The highest point on the salt is 46 feet below sea-level. The surface of the salt core is very irregular, no doubt due to the removal of great quantities of salt by circulating water. As at Avery Island, this is indicated by the variation of dips in overlying strata which would otherwise be horizontal or only gently flexed.

The salt core is in most other aspects very much like that at Avery Island. The salt has the same remarkable purity, the same crystalline structure, and there are the same vertical streaks, the darker being due to inclusions of anhydrite. There is, however, one notable difference: whereas the salt at Avery Island is remarkably hard, that from Weeks Island shatters readily under the blows of a hammer. There are also horizontal lines of weakness along which the



After A.C Veatch

FIG. 7.—Map of Weeks Island

salt breaks as though stratified. These are thought to result from pressure. The sections revealed in exploring the salt core show little variety as to the character of the sediments overlying and surrounding the stock. There is commonly a surface layer of clay from a few inches to 30 or 40 feet thick, followed by sand and gravel down to the salt. In a few of the wells beds of lignite from 3 to 5 feet in thickness were found just above the salt. Blue clay was also met with in some of the wells. The shaft passes through sand for the most part, with an occasional streak of gravel, and a 6-inch stratum of clay just

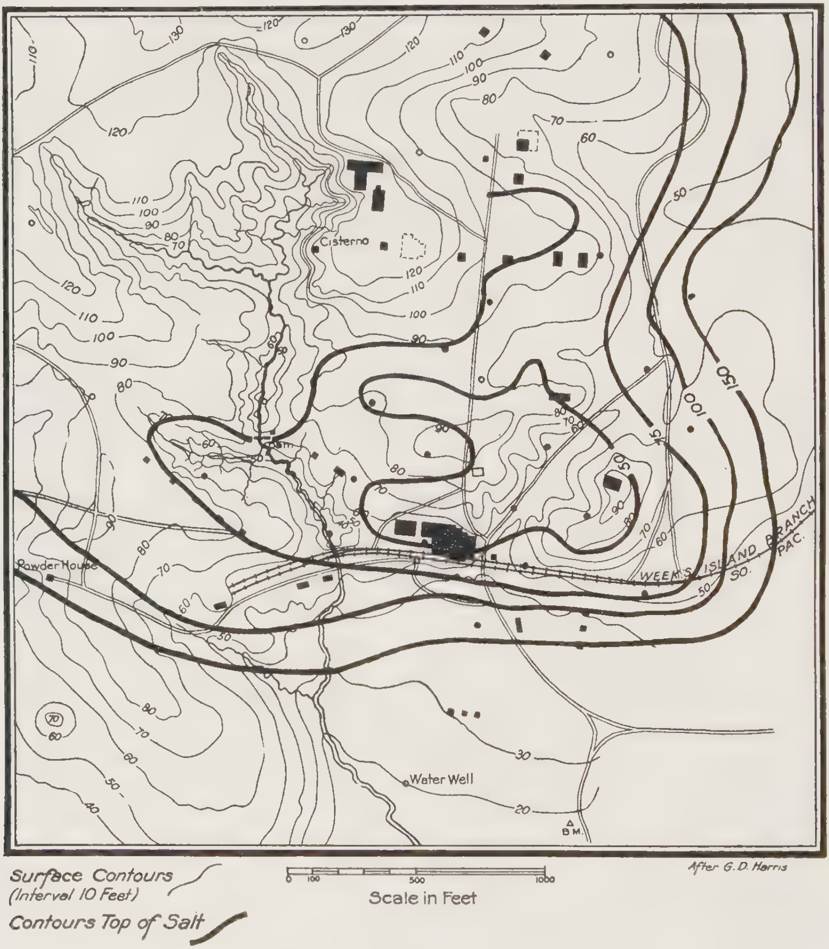
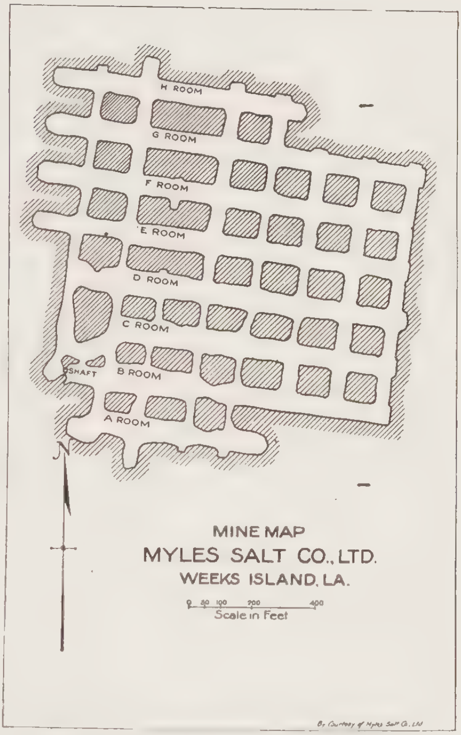


FIG. 8.—Map of Vicinity of the Mine, Weeks Island

above the salt. As at Jefferson Island and Avery Island, no important cap rock has been found in any of the numerous test holes.

SALT PRODUCTION

The mine on Weeks Island was opened and is still operated by the Myles Salt Company, of New Orleans. After lowering a cast-iron joint casing 10 feet into the salt mass, the shaft was continued downward for 35 feet, the cylindrical form being maintained. The shaft is lined with wood lagging. Surrounding this there is a wall of concrete 1 foot thick. Then at fairly even intervals there are four rings of asphalt from 3 to 5 feet in height and with bases 2 to 3 feet thick. Moreover, the surface of the salt was heated by hand torches and painted with asphalt. Below the tubular portion, the shaft is square and continues to a total depth of 645 feet.



By Courtesy of Myles Salt Co. Ltd

FIG. 9.—Mine Map, Myles Salt Co., Ltd. Weeks Island, La.

Mining operations are conducted in somewhat the same manner as at Jefferson Island and at Avery Island (Fig. 9). The salt is blasted down, loaded by compressed-air shovels into cars, and hauled to the shaft by electric locomotives. At the shaft the salt is passed through a crusher and falls into a bunker from which it is drawn into a 5-ton skip. Although the system is not balanced and but one skip serves the mine, the hoisting capacity is about 750 tons per ten-hour day.

Because of the incoherent nature of a large part of the salt, a greater percentage is crushed here than at the other mines. The mill is provided with automatic machinery for filling boxes with table salt, making, filling, and sewing bags with salt, etc. The salt is crushed and sorted to various degrees of fineness, including the finest powder, table salt, coarser grades for packing, and large chunks for cattle.

The total production of the mine from the time when it was opened in 1902 until the present is 2,047,308 tons. The past few years have been the most successful, the production for 1923 having been about 170,588 tons and that for 1924 about 200,000 tons.

EXPLORATION FOR OIL

About twenty years ago three wells were drilled a short distance from the island west of Shell Heap. These reached depths around 1,200 feet, but without finding even a trace of oil. More recently a hole was drilled to a depth of 900 feet on the east shore of the island northeast of Sugar House, but no indications of oil were found. In exploring the salt stock, a hole 919 feet deep was drilled on the edge of the island west of the shaft without striking salt. No trace of oil was found in this hole.

CÔTE BLANCHE

LOCATION

Côte Blanche is on Côte Blanche Bay in the western part of St. Mary's Parish. It is about 20 miles by straight line south of New Iberia, although by the automobile road the distance necessary to travel to reach it is considerably greater. In common with most of the islands of the group, it is nearly surrounded by marshes but is connected to the mainland by a raised dirt-way.

HISTORY

As far back as 1862, immediately after the discovery of salt on Avery Island, shallow pits were sunk here in a search for salt, but without success. However, it was still believed that there was a body of salt beneath the island, and from time to time various attempts were made to find it. In 1919 the Cecil Rhodes Company drilled six holes in the northeastern part of the island and then gave up the project.

In the spring of 1921 the Southern Salt Syndicate was organized, principally of business men from New York, Philadelphia, and New Orleans, for the purpose of finding and mining salt on the island. Drilling began in June, the work being carried on under Mr. C. J. Webre, of New Iberia, who was also a director in the company. Salt was soon found, and by June, 1922, fifty-four holes had been drilled and the contour of a part of the upper surface had been pretty well determined. Since the uppermost part lies two hundred and ninety-eight feet below the surface and two hundred and ninety-seven feet below the water-level, rather serious difficulties would be met with in sinking a shaft. For this reason, and also because of certain difficulties which have arisen over leases with land-owners, no attempt to mine the salt has yet been made.

PHYSIOGRAPHY

Côte Blanche is nearly circular in form and rises to an elevation of about 100 feet above sea-level (Fig. 10). While resembling both Avery Island and Weeks Island, it is much less rugged, smooth slopes being common and steep-walled ravines entirely absent. There is, however, a wave-formed bluff on the south side which is about 50 feet high. East of this bluff a long arm of sea marsh runs into the island. Rising abruptly from this is Oak Hill, the summit of which is the highest point on the island.

GEOLOGY

Surface. Because of the smooth contour of the island, very little can be learned of its geology from a study of the surface, which is covered for the most part by a brownish-yellow loamy clay. At one point near the northeast end of the island a gully exposes a rather clayey sand with gravel scattered through it. In the sea cliff on the south side of the island there is exposed a section which is given, in descending order, in Table IX.

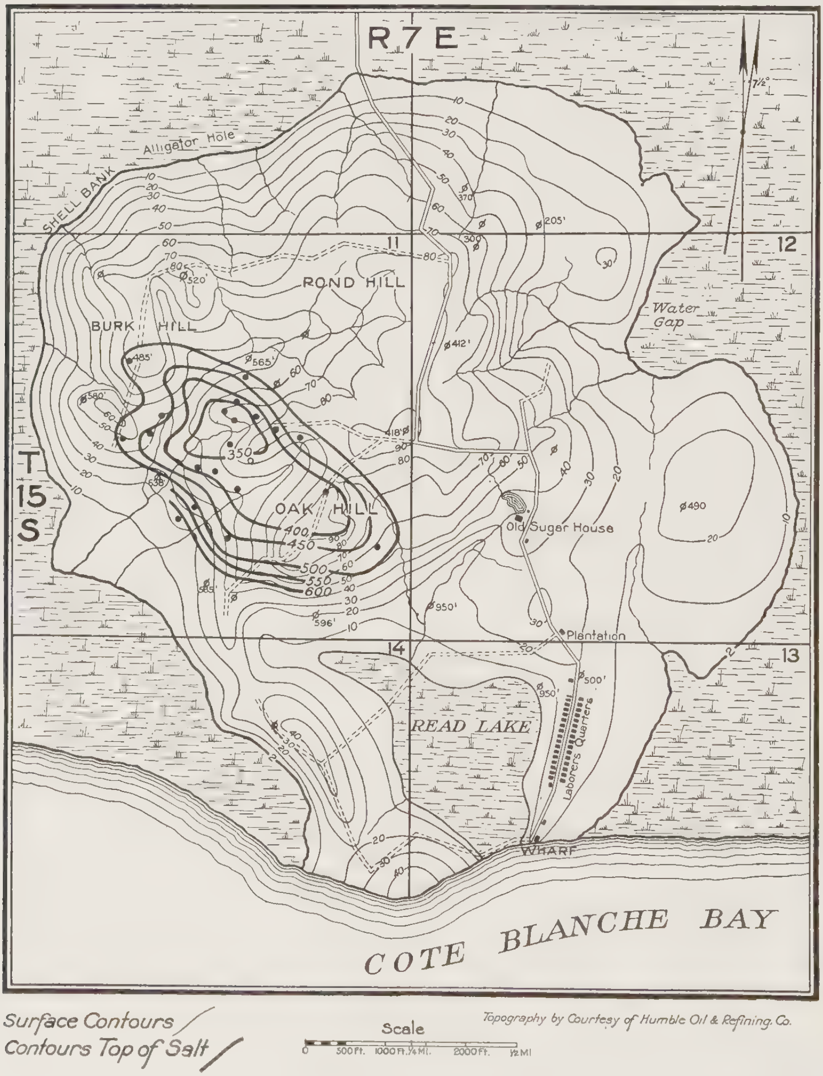
TABLE IX

SECTION ON SOUTH SIDE OF CÔTE BLANCHE

	Feet
Light-yellow clay containing some lime	11
Green or bluish-green clay	1
Reddish clay with limestone concretions	7
Fine red silt with thin clay partings every 6 inches	11
Practically the same with more clay	15
Grayish-yellow clay	2

Near the west end there is a fault, with downthrow to the northwest, which would seem to be due to slumping resulting from the solution of salt from below.

Subsurface.—The uppermost part of the salt dome, as determined by the numerous holes which have been drilled on the island, is shown in Figure 10, but this probably represents only a small portion of the entire mass. The evidence of slumping, as afforded by the



Topography by Courtesy of Humble Oil & Refining Co.

FIG. 10.—Map of Côte Blanche

faults in the sea cliff, certainly suggests that the salt stock extends nearly to the southern boundary of Côte Blanche. Wood Lake may be a sink hole resulting from the same cause.

The general conception that the islands were uplifted by intrusive masses of salt and that, therefore, salt underlies the greater part of each of the islands leads us to believe that it also extends beneath the northeastern portion of this island, where several holes failed to reach salt. Very likely deeper drilling would have been more successful.

The sedimentary beds overlying and surrounding the stock, so far as has been determined by drilling, are of the same general character as those associated with the stocks at Jefferson Island, Avery Island, and Weeks Island. They are almost entirely lenticular sands and clays which vary so greatly in thickness within short distances that exact correlation is practically impossible, and any dome structure which they might possess is completely masked. Only small lentils of cap rock from a few inches up to 4 feet in thickness have been found.

The holes drilled to outline the salt show conclusively that no oil occurs above it, but no hole has tested the possibilities of finding oil around the periphery. However, all of the island is under lease, some of it being in the hands of strong companies, and no doubt will some day be tested.

DEVELOPMENT

The development of the mineral resources of the island has not been carried beyond the prospecting stage.

BELLE ISLE

LOCATION

Belle Isle lies about 8 miles from the mouth of Atchafalaya River near its intersection with Myrtle Bayou, a distributary. It is isolated, being surrounded by a network of bayous and a great sea marsh, but can be reached by boat from Morgan City, a town on the Southern Pacific Railroad about 15 miles to the northeast.

HISTORY

The discovery of rock salt in drilling for artesian water on Jefferson Island in 1895 and the increasing difficulty of mining salt on Avery Island, due to water in the mine, led to explorations for salt on the other islands of the group. In November, 1896, Captain A. F. Lucas began operations on Belle Isle. In December salt was found in the first test hole at a depth of 373 feet. In 1897 and 1898 the Gulf Company bored thirteen additional holes, and in August, 1898, started a shaft on the site of hole No. 11, where a sill of salt was found at a depth of 103 feet and a solid mass at 140 feet. The shaft was sunk to a depth of 390 feet. A heading was then driven eastward a distance of 340 feet, when water rushed in and rose in the shaft to sea-level within two hours.[50]

A second shaft was started at a distance of $\frac{1}{4}$ mile southwest of the first, but trouble with quicksand and soft clay was encountered from the beginning. In spite of strenuous work and attempts to freeze the soft materials, the work had to be abandoned after a depth of about 200 feet had been reached. Salt was then raised by pumping it as brine. In this manner several thousand tons were obtained, but, owing to the fact that the salt at this locality is impregnated with oil, it was found difficult to crystallize it, and it was also left with rusty stains. The unconsolidated character of the overburden permitted the escape of brine, and caving was threatened. It became evident that this process would reduce the island to sea-level, and it was abandoned.

In 1906 the New Orleans Mining and Milling Company took over the property and drilled two wells near the north end of the island in an effort to find oil. Although the deeper of these reached 2,411 feet and is less than 1,000 feet north of the old mine shaft, it failed to find salt, indicating that the northern face of the stock is very abrupt. This well reported good showings of gas and oil between 1,396 and 2,989 feet, but no commercial accumulations were found.

During 1907 and 1908, I. N. Knapp drilled three wells on the island, the northernmost of which, No. 1, close to the first shaft, entered salt at about 140 feet and continued in it to 3,171 feet.[53]

During 1916 and 1917, under the stimulus of the demand for sulphur for war purposes, a syndicate of New York capitalists was organized to explore the island. Under the direction of Captain A. F. Lucas, six wells were drilled. In the course of this work the salt mass was found to be of greater extent than was previously thought. A narrow belt of impure sulphur-bearing rock was found extending across the northern part of the island, but it was not considered of sufficient importance to warrant exploitation, and work was discontinued.[54]

In June, 1921, the island was taken over by the Union Sulphur Company. Seven test holes have been drilled and an eighth is now under way.

PHYSIOGRAPHY

Belle Isle is a rudely triangular area with a single range of hills along its northwest side (Fig. 11). This range culminates in four peaks, the highest of which, Lookout Hill, on the westernmost point of the island, is 80 feet high and is a landmark visible for miles from the surrounding marshes. The other high points of the range are

Green Tree Hill, Bald Hill, and Shaft Hill. The rest of the island is a gently sloping, slightly elevated area which extends southeastward from the hills. Willow Pond is a shallow, wooded, fresh-water pond almost in the center of the island.

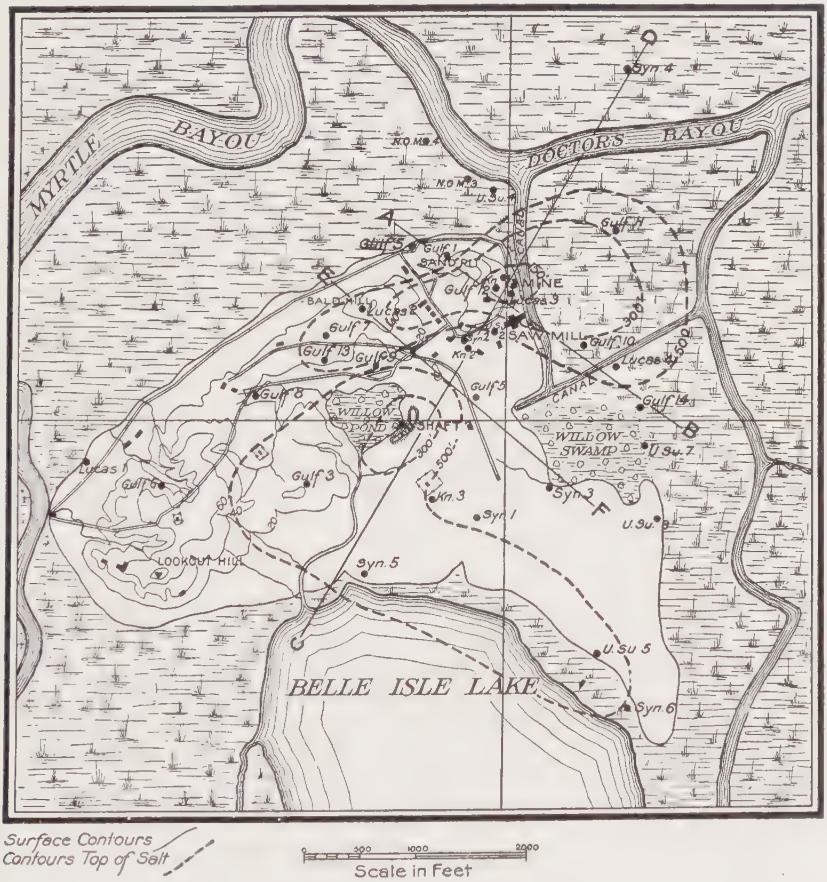


FIG. 11.—Map of Belle Isle

GEOLOGY

Surface.—With the exception of a small area on the eastern side of Shaft Hill, the island is covered with unconsolidated Recent sediments, the surficial layer generally being a grayish-yellow to yellowish-brown clay. This is commonly underlain by a thick mass of sand, but the beds are lenticular and in some localities the sand is interbedded with lenses of clay, gravel, and shale. The surface clay is particularly well developed on the western part of the island. South of Willow Pond there are several springs, and although this patch of gravel is well elevated above the sea marsh, it is covered with salt grasses. Formerly a spring south of shaft No. 1 yielded small quantities of oil.

On the eastern slope of Shaft Hill there are small outcrops of a gray, iron-stained, rather soft, broken limestone which contains small amounts of galena and chalcopyrite. It is best exposed in a number of pits dug in looking for stone suitable for jetty work. About 150 yards northwest of the limestone outcrop there is a sand pit in which is exposed the section shown in Table X.[50]

TABLE X

SECTION NEAR SHAFT HILL, BELLE ISLE

	Thickness (Feet)
Dark humus-stained clay	0.5
Mottled gray to yellowish-brown clay	2
Mottled gray and brown clay grading downward into finely laminated gray clay	4–7
Massive dark-gray clay	1
Black clay with some pyrite	1–3
Dark conglomerate containing invertebrate remains	0.7
Irregularly bedded brown to white sand with clay pockets and traces of sulphur	2–5

These beds strike approximately N.75° E. and dip 23° NW. The fossils in the dark conglomerate bed are all species represented on the Gulf Coast today. It is therefore clear that the latest movement in the salt mass has been very recent.

Subsurface.—Such information as is available shows that the subsurface geology of Belle Isle is of greater complexity than that of the other members of the group, and although considerable exploration has been done by drilling and shaft-sinking, our present knowledge is insufficient to permit of satisfactory description.

Salt.—The form of the upper portion of the salt stock is very irregular. The results of the first wells by Lucas and the Gulf Company suggest that the topographic ridge along the northwest side of the island reflects the salt core as to both size and form. While this is true in some degree, the more recent Syndicate and Union Sulphur Company wells show that the salt core is much larger than was formerly believed, for it certainly extends southward to Belle Isle Lake and very likely beneath it for some distance (Fig. 11).

The salt occurs in several forms: large transparent crystals 1 to 8 or more inches long, either in the salt stock proper or scattered through dark-colored clay associated with the upper part of the salt mass; smaller crystals in masses having the appearance of coarse crushed ice or inclosing pieces of dark clay, which gives the salt a dirty earthlike appearance. Gypsum crystals are occasionally found with the large salt crystals.

TABLE XI

ANALYSES OF LIGHT AND DARK SALT FROM BELLE ISLE

	Dark Salt	Light Salt
Sodium chloride	92.750	96.405
Calcium sulphate (soluble)	....	3.051
Magnesium chloride	....	.074
Magnesium carbonate	2.01	....
Sodium carbonate	.067	....
Sodium sulphate	.836	....
Calcium carbonate	1.804	....
Calcium chloride	....	.226
Ferric and aluminic oxides (Fe_2O_3 and Al_2O_3)	.500	.025
Insoluble matter	3.325	.059

Unlike that at the other islands, the salt at Belle Isle is very impure when first struck, but its purity seems to increase with the depth. The dark, impure salt somewhat resembles the dark streaks of salt at Avery and Weeks Islands, and upon analysis is also found to contain anhydrite. In addition, it contains some gypsum and traces of oil. The difference in chemical composition between the light and dark salt at Belle Isle is shown by the analyses given in Table XI.[50]

The salt mass is overlain and surrounded by sands and clays similar to those found on the other islands. Associated with them, and with the salt, are other materials which have not been found around the other domes of the group. Of these sulphur, barite, galena, sphalerite, pyrite, chalcopyrite, and oil are the most noteworthy.

With the exception of sulphur, these were all found in sinking the first shaft. The section passed through is as shown in Table XII.[50]

The white limestone in the salt near the bottom of the shaft is different from any other yet reported in the Gulf Coast district. It resembles chalk and is composed of extremely small, rounded grains, like those in an oölite except that they are much smaller.

Oil and sulphur.—A number of test holes drilled on the island have encountered oil showings, sulphur rock, and the top of the salt stock. A summary of the results as regards these materials is given in Table XIII.[51]

TABLE XII

SECTION OF MINE SHAFT ON BELLE ISLE

	Depth (Feet)	Thickness (Feet)
Clay	0–4	4
Hard sand	4–13	9
Blue clay	13–30	17
Blue clay and sand	30–40	10
Hard clay and gravel	40–63	23
Blue clay with crystalline masses, 1 to 7 inches in diameter, of barite, galena, sphalerite, pyrite, and chalcopyrite	63–68	5
Blue clay and shells	68–95	27
Impure black limestone and barite	95–96.5	1.5
Blue clay with masses of barite near the base	96.5–103	6.5
Dark clay with large crystals of salt	103–16	13
Dark clay with oil	116–17	1
Salt with dark clay	117–42	25
Discolored salt	142–62	20
White limestone	162–62.7	0.7
Dirty salt, purity increasing with depth	162.7–75	12.3

It is of interest to note that Knapp No. 2 reports 590 feet of gypsum, anhydrite, and sulphur immediately above the salt, and that Lucas No. 2 passed through 60 feet of sulphur rock at the same horizon. These two wells must have encountered the sulphur deposit at its maximum thickness, for Syndicate Nos. 3 and 4 found only 5 feet of sulphur rock, and Nos. 1, 5, and 6 found practically none. Although Knapp No. 1 and Gulf I report sulphur, the results of later drilling show that in neither case could there have been any great amount. It is therefore clear that the sulphur deposit is of very limited extent (Fig. 12).

Knapp No. 1 is of particular interest because of the oil showings found at several horizons. This well entered the salt at a depth of 140 feet and continued in it to 3,171 feet. In the last 600 feet several occurrences of limestone, sand, anhydrite, sulphur, and oil were noted. A canary-yellow oil of 37° Baumé was found a short distance above the salt, at a depth of 125 feet. The well also encountered gas at several places in the salt, and dark-red oil of 37° Baumé in the salt from a depth of 1,500 feet to the bottom of the hole. For the last 300 feet this well labored very hard on account of heavy gas pressure, and was abandoned at a depth of 3,171 feet. Oil was also found in Gulf I. This oil is very light-color and so pure that it has been successfully burned in lamps without refining. There is also some gas. Although there seems to be but a small flow when allowed to escape freely, it has developed a pressure of 1,000 pounds per square inch

TABLE XIII

Summary of Explorations on Belle Isle

Name	Well No.	Elevation + (Feet)	Oil Showings at (Feet)	Sulphur Rock at (Feet)	Top of Salt (Feet)	Total Depth (Feet)
Lucas	1	5	....	....	....	590
Lucas	2	13	Traces	276	335	410
Lucas	3	7	110–25	*110–25	135	170
Lucas	4	5	135–275	*135–275	325	....
Gulf Shaft	1	7	116–17	none	117	326
Gulf Shaft	2	5	none?	16.0–190	210	196
Gulf Shaft	H	5	none	340–91	....	420
Gulf Shaft	I	20	303, 940, 985, 1,086, 1,105, 1,212, 1,365, 1,370	256–85, 870, 1,206	1,545	2,450
Gulf Shaft	J	....	none	none	....	600
New Orleans Mining Co.	2	.	....	....	....	1,740
New Orleans Mining Co.	3	....	1,396, 1,506, 1,584, 2,190, 2,270, 2,389	none	....	2,411
Knapp	1	..	143, 160, 1,850 1,965, 2,100, 2,190, 2,500, 2,722, 2,900	*145–59, 2,606–28	150	3,171
Knapp	2	....	390	290–880	880	890
Knapp	3	....	none	none	550	800
Syndicate	1	....	none	none	....	481
Syndicate	2	....	246–81	286–341	....	341
Syndicate	3	....	none	391–96	445	566
Syndicate	4	....	320–499	494–99, *565–751	....	715
Syndicate	5	....	none	none	490	534
Syndicate	6	....	none	*415–505	505	545

* Trace only.

when shut in. Knapp No. 2 is also interesting, as small quantities of very light oil can be obtained from it even at the present time.

Of the eight holes put down by the Union Sulphur Company, only a few are of any particular interest. In No. 2, drilled a short distance from shaft No. 1, soft limestone was found from 300 to 320 feet. Below this there was about 80 feet of soft material containing limestone and gypsum. It is reported that some sulphur was also present. From 400 feet to the bottom, 2,200 feet, the hole was in massive salt which was fairly clear except for numerous black specks resembling pepper. Wells Nos. 3 and 7 are said to have encountered the same mass of limestone and gypsum, with some sulphur, found in No. 1. No. 4 was drilled to a depth of 3,900 feet and was in shales and clays, with some beds of sand, practically all the way. No. 5 also found lime, gypsum, and a little sulphur.

Any prediction as to the future of Belle Isle as a producer of oil or sulphur would be hazardous. However, the high gas pressure and the oil so commonly found within the salt body itself would seem to indicate that there is a pool of oil somewhere in the immediate vicinity.

Structure.—The dip of the beds penetrated by the drill on the northwest side of the island is away from the island, and therefore conforms to the structure generally recognized as typical of salt domes; that is, it appears that the salt has been thrust up through sedimentary beds, upturning them immediately around its periphery. The older beds found on the north side of the ridge immediately above the salt are not found on the south side, evidently because this is toward the interior and represents what was once the higher part of the island, and the beds have been removed by erosion. It is of particular interest to note the recency of the movement, as evidenced by the tilted beds containing Recent shells described on another page.

PALEONTOLOGY

The fossils from the sand-pit section are poorly preserved, but so far as they can be identified, they represent a cold-water fauna quite different from the warm-water fauna of the Pliocene.[50] Veatch has called attention to their resemblance to some phases of the Chesapeake Miocene, but expresses the belief that they are Pleistocene,

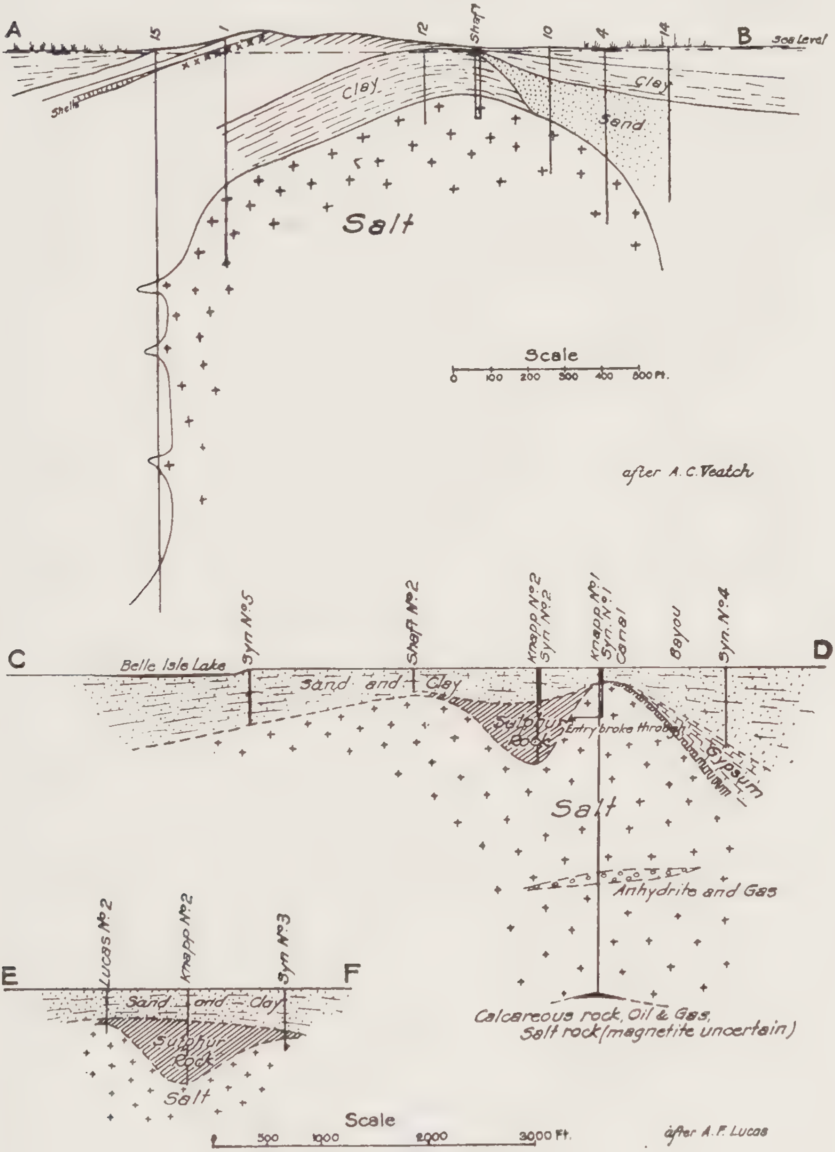


FIG. 12.—Belle Isle—Sections

which view obtains at the present time. The following is a list of the species:

Ostrea virginica
Lithopaga, cf. *caudigera*
Scapharca transversa
Gnathodon cuneatus
Dosinia sp.
Cardium muricatum
Corbula sp.
Mactra sp.
Venus cancellata
Semele truncata
Fulgar canaliculatum

REMARKS

One of the most important problems presented by the Five Islands is the nature of the sediments surrounding the salt stocks, particularly with reference to the depths at which the various Tertiary formations lie and the possibilities of finding oil. At Avery Island a log was found at a depth of 2,643 feet in such a state of preservation that it could hardly be older than Quaternary. There is no conclusive evidence here, nor at the other islands of the group, of the depth to the youngest Tertiary rocks, although the occurrence of oil at Belle Isle suggests that they are probably within reach of the drill.

The depths to which the salt masses extend have not been definitely determined, but if the salt is of Permian age it seems to indicate at least 10,000 or 12,000 feet. At the Humble dome in Texas, the salt core was penetrated by the drill, proving more than 4,000 feet of solid salt with no indication that the bottom was being approached. It therefore seems almost certain that the salt cores beneath the Five Islands extend to depths exceeding 5,000 feet, and they may extend to depths of 10,000 or even 15,000 feet.

Besides being interesting in themselves, the Five Islands deserve special attention because of the light they throw on some of the more general problems presented by the Gulf Coast salt domes.

Nowhere else in this region do we find such convincing evidence of the intrusive nature of salt stocks as at Avery and Weeks Islands. The elongated crystals of salt, the nearly vertical bands in the salt, and the parallelism of these bands in horizontal section to the periphery of the salt indicate that the salt has come to its present position by flow. The mass of tough red sandstone within the salt stock at Avery Island is further evidence of this for two reasons: first, its long-drawn-out, irregular form, with considerable shattering, is most suggestive of flow; second, its lithological character is altogether different from that of the rocks surrounding the stock, and it must therefore have been brought to its present position from elsewhere, presumably from below. This rock also suggests the age of the salt, for it closely resembles certain Permian rocks in the Texas Panhandle, even in such details as fineness of grain, secondary growth around the quartz grains, and coloring matter. Furthermore, such rock in the Texas Panhandle is often associated with great beds of salt. This evidence, of course, cannot be considered as conclusive, but it is certainly suggestive.

The origin of the cap rock above the salt in the Gulf Coast is a matter of some controversy, but there seems to be little doubt that the cap is in part the residue left by the solution of the upper portion of the salt plug. At Jefferson Island, Avery Island, and Weeks Island, where the salt is rather pure, there is practically nothing that can be called true cap rock. Very little is known about either the purity of the salt or the nature of the cap at Côte Blanche. At Belle Isle the salt is impure and there is considerable cap rock present, and the cap-rock material is essentially the same as the impurities in the salt. Besides impurities scattered through the salt, there are within the salt mass itself beds of limestone, gypsum, and anhydrite. The solution of a mass of salt, leaving behind such beds, and a concentration of the scattered impurities would certainly result in a heavy cap rock. While much of the cap-rock material would retain its original character as a bedded deposit, it would all, in reality, be the residue from the dissolved salt. Even such heavy cap-rock masses as that at Spindletop could easily result in this manner.

The Five Islands present considerable evidence of recent uplift. The elevated position of Recent fossils at Jefferson Island shows that the island was probably uplifted in very late Pleistocene or post-Pleistocene time. At Belle Isle recent uplift is evidenced by beds containing Recent fossils dipping at an angle of 23°. None of the islands shows any evidence of elevated beaches, although they are at tide-level on a coast of recent emergence. Consequently they must have attained their present elevations since the most recent general uplift of the Gulf Coast.

Perhaps every geologist who has worked in the Gulf Coast district has made some attempt at determining tectonic lines along which the salt stocks have risen. With perhaps but one exception, every line proposed has been disputed by evidence quite as convincing as that by which it was supported. The one exception is the line of the Five Islands. The islands lie in practically a straight line. Also, they are very much alike; in fact, every member of the group resembles every other member more closely than it resembles any other dome in the entire Gulf Coast district. This statement covers a great deal, including the fact that they have all been recently uplifted. It would therefore seem that the Five Islands do mark the position of a tectonic line.

COMPARISON OF FIVE ISLANDS WITH THE GREAT SALT DEPOSITS OF THE WORLD

In thickness and purity the salt masses beneath Jefferson Island, Avery Island, and Weeks Island easily outrank any others known in this country. In Europe the famous Strassfurt deposits, of Permian age, show only 685 feet of pure rock salt. The salt wells in strata of the same age at Sperenberg, near Berlin, pass through about 3,800 feet of rock salt. The famous Wieliczka deposits of Galicia, Austria, have an aggregate thickness of 4,600 feet. But this does not represent the thickness of a single mass of salt such as underlies each of the Five Islands. The saliferous formations of Wieliczka consist of lenses of salt separated by beds of clay, marl, and anhydrite. The great deposits of the Salt Range in India are associated with beds of clay, their aggregate thickness generally running from 300 to 700 feet and never exceeding 1,200 feet.

While these various deposits are of considerably greater areal extent than those of the Five Islands which are being mined, there seems little doubt but that the latter rank first of the world's deposits for thickness and purity; they may even rank first as to total tonnage of workable salt.

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THE JENNINGS OIL FIELD, ACADIA PARISH, LOUISIANA[1]

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ABSTRACT

The Jennings oil field was one of the earliest oil fields of the first class on the Gulf Coast. It is on a dome in Tertiary sediments. Although the salt has not been drilled into, limestone which has never been drilled through and which resembles cap rock underlies the main part of the field, and is taken to indicate the presence of a salt dome. There is a surface mound that is probably the remnant of a salt dome mound and a depression that in part is probably a "central depression." The Jennings field has been one of the most prolific of the Gulf Coast oil fields, and had many long-lived wells with enormous total production.

INTRODUCTION

LOCATION

The Jennings oil field, known also as the "Mamou," or "Evangeline" oil field, is located in Acadia Parish in southern Louisiana, 185 miles west of New Orleans, and 175 miles east of Houston, Texas. It is 35 miles east of Lake Charles, and 7 miles northeast of the town of Jennings on the Southern Pacific Railroad. The field is near the center of T. 9 S., R. 2 W. The field is reached by auto from the towns of Jennings or Crowley.

HISTORY

The Jennings oil field is one of the oldest oil fields of the first rank in the Gulf Coast. Attracted by the escape of gas in springs which had long been known by early settlers, the Jennings Oil Company, early in 1901, engaged the Heywood Brothers of Beaumont to drill a test well, to be located in Section 46 near the northeast corner of a block now known as the Gulf Refining Company's Jennings-Clemont lease. In August of 1901, eight months after the famous Lucas well at Spindletop came in, the Jennings well encountered a loose sand at 1,882 feet (564 m.), and blew in spraying oil and sand in considerable quantity; after blowing wild for several hours, the well choked up and was finally abandoned. The next test, the Southern Oil Co.'s No. 1, was unfortunately located far to the south of the real field and was abandoned below 2,500 feet (750 m.), without finding oil. Profiting by this experience, the Southern Oil Company located their next test 250 feet northwest of the original Jennings Oil Company's No. 1. At a depth of about 1,850 feet (555 m.), this well also encountered a loose broken sandy formation, blew in, and made considerably more oil than No. 1 Jennings Oil Company but not having a screen soon choked up and was lost.

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[1] Published by permission of the Rycade Oil Corporation.

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The field now needed no further recommendation; extensive exploration was quickly started; and within the next few months several producers were completed. It was not, however, until June, 1902, that the first really successful well was brought in, the Jennings Oil Company No. 2, also drilled by the Heywood Brothers, and located 100 feet (30 m.) southwest of their No. 1, the pioneer test of the field. The field produced slightly over 548,000 barrels (73,060 tons) of oil during 1902.

From then on the producing territory was gradually extended in every direction. In 1903, the Superior Oil Company extended the field westward, and the Crowley Oil Company extended it to the north and east, but wells drilled on the hill and far out from the field were dry.

In January 1904, the Chicago Jennings well No. 2, extended the field to the south; also in this year the Producers Oil Company on their 40-acre Latrielle tract extended the field to the southeast. Operations increased steadily until in February, 1904, Jennings had 35 producing wells. Over 6 million barrels (833,300 tons) of oil were produced in the last six months of that year.

The next year, 1905, was discouraging in many respects. As a consequence of the reckless waste of gas and the correspondingly diminishing gas pressure, many of the older wells had to be put on the pump, and salt water made its appearance in the older wells. To make matters worse the flood of oil from the great Humble field caused a slump in the price of crude to 16 to 18 cents per barrel.

The peak of production for the Jennings field, nevertheless, was reached in 1906, with a production for the year of over 9 million barrels (1,250,000 tons). Production declined rapidly in 1907, and again in 1909, and then gradually, until the present daily average is about 500 barrels (69 tons) per day for the field.

From time to time, periodical increases in production take place in the old field and systematic exploration for flank sands may yet revive the activity of the field. The recent renewed attempts to find deeper oil have been unsuccessful. On the north edge of the field in Section 48, the Coastal Oil and Fuel Company drilled to 4,302 feet (1,336 m.) and failed to find oil. Recently the Rycade Oil Corporation on the southeast side of the field abandoned their well at 2,355 feet (706 m.) in caprock.

PHYSIOGRAPHY

REGIONAL PHYSIOGRAPHY

The physiographic province in which the salt domes of Louisiana and Texas occur is the Gulf Coastal Plain (Fig. 1). In southern Louisiana and southeast Texas, it is composed of the Coastal Prairie, the Kisatchie Cuesta, other cuestas farther inland, and the Mississippi Valley and Delta. This physiographic province has been discussed, and its component features have been described elsewhere by the senior author.[1]

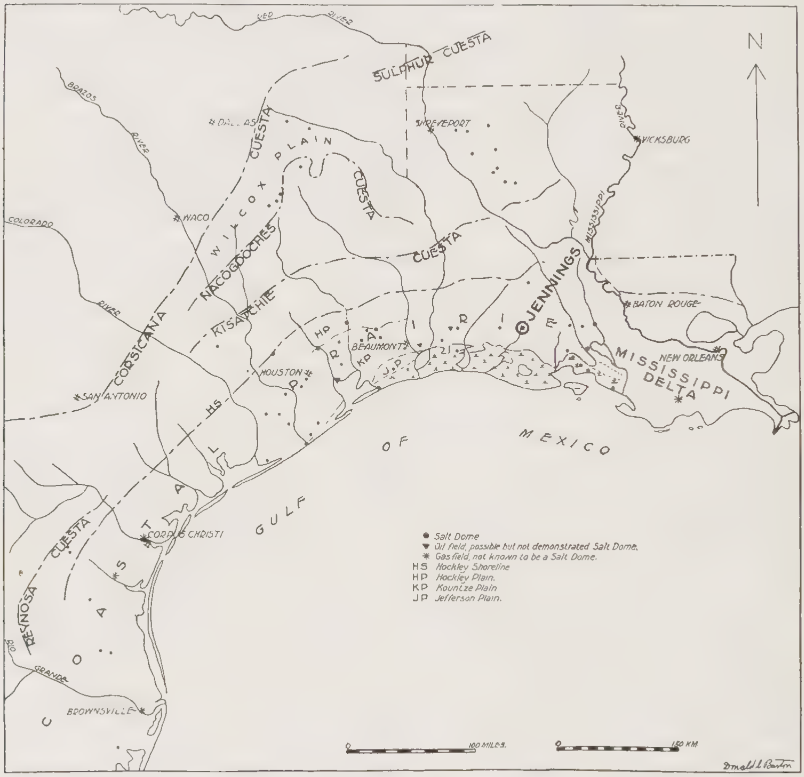

FIG. 1.—Physiographic sketch map of the Texas Louisiana gulf coast, showing the position of the Jennings Field.

The Jennings salt dome lies about midway of the Coastal Prairie belt. The area immediately around the dome has been much dissected by the rivers, Bayou Nezpique, Bayou Cannes, which unite just below the dome to form Mermentau River. To the east and to the west of that area, is a broad flat prairie which belongs to one of the intermediate Pleistocene plains, perhaps the Hammond. The dome itself, is on a narrow strip of prairie between Bayou Nezpique on the west, and Bayou Cannes on the east. The crest of this interstream ridge seems probably to be a remnant of the prairie level of this region.

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[1] Barton, Donald C., "The Pine Prairie Salt Dome," *Bull Amer. Assoc. Petrol. Geol.*, Vol. 9 (1925), pp. 739–42.

PHYSIOGRAPHY OF THE DOME

The topography at the dome consists of a broad, shallow, irregular basin-like depression which is drained by a brook and its ramifying branches, and of a low, irregular hill to the east. The basin is about 1½ miles in diameter and covers a large part of the richly productive area in the center of the field as well as a much larger area of much poorer productive territory to the west. The origin of the basin may be explained by erosion, by collapse due to solution of the top of the salt dome, or by settling consequent upon the extraction of the oil. It is certain that there has been erosion. The basin was considered by Harris to be one of the central depressions characteristic of salt domes. It is very much larger and more ill-defined than the typical central depressions of salt domes and on the west extends well off the probable area of the salt. There seems to be a fair possibility, however, that the basin is in part a salt-dome of central depression. According to reports of an observer familiar with the field, the basin in considerable part has been caused by settling since the field came in. Non-instrumental evidence based on casual observation and memory cannot be accepted as conclusive, but the reported observation is decidedly suggestive, especially in the light of the results of an investigation of the Goose Creek field by one of the Gulf Coast oil companies.[1] On the basis of a priori reasoning, it seems reasonable to expect distinct settling of the surface in the noncap-rock oil fields of the first class.

(1) Sediments such as the Gulf Coast oil sands are laid down

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[1] Wallace E. Pratt and Douglas W. Johnson, "A Recent Local Subsidence of the Gulf Coast of Texas," *Geol. Soc. of Amer. Proceedings* (preliminary list of abstract of papers), Thirty-eighth Annual Meeting, 1925.

with an excess of pore space, that is, the individual grains are not fitted together in such a way as to give the minimum volume and minimum pore space. In the case of finer sediments, and less so in the case of the coarser sands laid down under water and never dried out, the individual particles or grains must be held apart in some degree by the included water. (2) Compression of the sediments can take place only to the amount of the expulsion of the interstitial fluids. (3) In buried sediments, there must be a tendency toward expulsion of the interstitial fluids and compression of the sediments under the weight of the overlying beds. (4) But in the case of the Gulf Coast beds, this tendency must be greatly hindered by the fact that the sands tend to be lenses in a predominant massive clay-shale section. (5) In the case of the Gulf Coast oil sands which are Tertiary in age, and therefore, not of great geologic age, it seems reasonable to expect that the beds have a potential capacity for shrinkage consequent upon the withdrawal of the interstitial fluids. (6) Contemporaneously with the extraction of fluids from within the productive area and the immediately surrounding drainage basin, a tendency should be set up for flowage inward from the whole surrounding region. This flowage, however, can take place only slowly through fine, silty sands, such as those at Jennings, and will be yet further retarded by the lensing and faulting of the sands, and cannot keep pace with the relatively free extraction of oil and water through the wells. The column of sediments, therefore, should shrink to the extent of the difference between the volume of water and oil that flows in and the volume that is extracted. (7) If the assumption is made that the field has produced twice as much salt water as oil, and if the fluids are withdrawn from an area four times the productive area, the oil and salt water extracted if spread over that total drainage area would have a thickness of a magnitude of 50 feet (15 m.) vertically.[1]

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[1] Total production of field equals 46 million barrels (6,388,000 tons) of oil = 1,930 million gallons = 7,277.8 liters = 7.8 million cu. meters. If production of salt water is twice that of oil, total volume of fluid = 23 million cu. meters. Production came from an area 2,000 feet (600 meters) square = 0.36 million sq. meters. If fluids are drawn from an area four times as large as productive area, drainage area = 1.5 million sq. meters. If extracted fluids were spread evenly over drainage area, they would cover it to a depth of 15.3 meters, or 50½ feet.

The settling necessary to account for the basin is 7 to 10 feet. The shrinkage in the sediments would be spread over 300 feet of section, about 40 per cent sand, and would represent a contraction of volume of the whole zone to the extent of 3 to 4 per cent, or a contraction of the volume of the sands to 7 to 8 per cent. In view of the magnitude of withdrawal of fluids, it seems to the senior writer that there is warrant for consideration of the theory of the formation of the eastern portion of the basin in part at least, through settling consequent upon the extraction of the oil and salt water.

The low hill on the Arnaudet and Latreille tracts on the east edge of the oil field would seem probably to represent the remnant of a salt dome mound. It is irregular in shape with a N.NE.–S.SW. axis, and a SE.–NW. axis. It rises 13 to 16 feet above the general level of the prairie west of the oil field and 8 to 13 feet higher than the general prairie level for 3 to 4 miles to the north. As it rises so definitely above the normal level prairie level, the hill seems to be an obscured salt dome mound.

GEOLOGY

SURFACE GEOLOGY

The beds exposed at the surface at Jennings (Fig. 2) are Pleistocene sands, sandy clays, and clays. In southeast Texas and southwest Louisiana a division of the Pleistocene beds is possible into the Lissie sandy member on the north and the Beaumout clayey member on the south. Farther east in Louisiana this distinction is not so clear; the Beaumont clay becomes much sandier, and toward Opelousas, Lafayette, and Abbeville it becomes decidedly loess-like. The Jennings dome lies in the vague zone between the Lissie and the Beaumont. The beds exposed at the surface over the dome seem to be those normal to that region.

SUBSURFACE GEOLOGY

The Texas and Louisiana Gulf Coast oil fields are associated with two main types of geologic structure: the salt dome type as at Spindletop, and the non-salt dome type as at Goose Creek. Although salt has never been actually encountered in the field, Jennings seems probably to be of the salt dome type.

Salt domes are characterized by quaquaversal dipping sediments around a central salt core. A mantle of caprock, in many cases, immediately overlies the salt core. The shape of the central salt core may be elliptical in plan as in the case of Stratton Ridge, or, more commonly, nearly circular as at Spindletop. The diameter of the salt core varies: where the core is elliptical, the major diameter may be as much as 12,000 feet (3,600 m.), and the minor diameter two-thirds as much, as at North Dayton; where the core is circular, the diameter is from 2,500 feet (750 m.) as at New Iberia, to 3 miles (5 km.) as at Humble. The thickness of the salt core of the domes is as yet unknown. At Humble the top of the salt is around 1,400 feet (425 m.), and the Texas Company's Wheeler Pickens well was abandoned

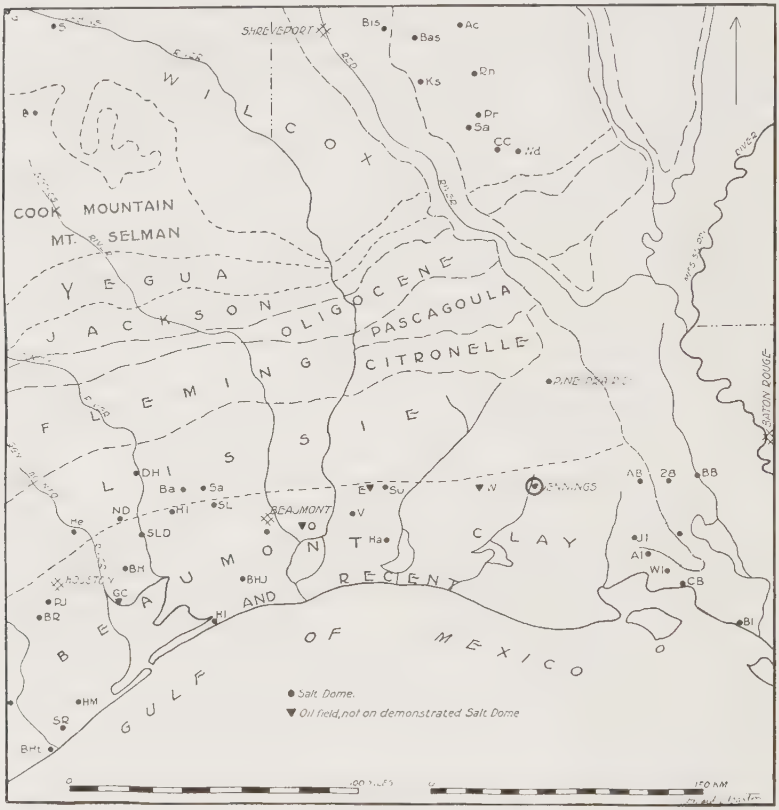

FIG. 2.—Geologic sketch map of Louisiana and southeast Texas

at 5,410 feet (1,623 m.) still in rock salt. The depth from the surface to the salt varies from a few feet, as at Avery Island, Louisiana, to some 2,300 feet (690 m.) below the surface, as at Markham. The top of the salt is commonly nearly flat and the edges are nearly vertical. In many of the Coastal oil fields, the salt is topped by a mantle of cop rock of varying thickness, size, and shape. It is often very porous and even cavernous. In some cases, it yields large amounts of oil as at Spindletop, or it may be entirely devoid of oil, as at Damon Mound. The thickness of the cap rock varies from a few feet to 1,000 feet (300 m.), or more. The strata surrounding the salt core are, for the most part, loose, unconsolidated sediments, and dip in all directions from the salt core.

The cap rock and the somewhat characteristic doming seem to indicate that Jennings belongs to the salt dome, or Spindletop type of oil field. The salt has not yet been drilled into, and is not actually known to be present. But no wells rightly located to encounter the salt have been drilled deep enough to prove, or disprove its presence. The data available in regard to the cap itself are rather scanty. The following wells encountered the cap:

Very slightly south of the center of the field:
  Producers Oil Co.'s Houssiere Latreille No. 74, at 2,012 feet....603 meters
On the southeast side of the field:
  Rycade Oil Corp.'s Houssiere Latreille No. 1, at 2,355 feet....706 meters
    (Abandoned in cap......................at 2,660 feet....798 meters)
  Producers Oil Co.'s Houssiere Latreille No. 81, at 2,398 feet....719 meters
On the south side of the field:
  Producers Oil Co.'s Houssiere Latreille No. 101, at 2,600 feet....780 meters
On the southwest side of the field:
  Gulf Rfg. Co.'s Jennings-Heywood No. 40, at 2,693 feet....808 meters

On the east side of the hill: an unnamed well at the north edge of the Houssiere-Latreille tract is some times spoken of as having gone into the cap at around 2,200–2,300 feet (700 m.). The writers, however, have not been able to confirm this report. Since no well has been drilled through it, the thickness of the cap is not known. From the depth to which the Rycade Oil Corporation's Houssiere Latreille No. 1 was drilled into it, the cap is more than 300 feet (90 m.) thick.

The lithology of the cap is not well known. Until our own well, the Rycade Oil Corporation's Houssiere Latreille No. 1, went into it, we could get no authentic information in regard to the character of the cap, and in that well only a few cores were taken in the cap. The upper part of the cap seems like a disintegrated granular limestone. When the driller went into it, he logged it as sand and in the Producers Oil Company's Houssiere Latreille No. 81, it was apparently logged as sand without being recognized. A core from a depth of 2,393 feet (727 m.) was composed of a soft, very friable, finely granular limestone. It was finely banded with alternating black and white bands, 1 to 4 cm. thick. A core from a depth of 2,426 feet (737 m.) was of limestone very similar to that of the preceding core, except in not being friable, and in being much harder. It is not known whether the limestone is underlain by a gypsum cap.

The extent of the cap is indicated by the negative control on the north of the Coastal Oil and Fuel Company's well drilled in Section 48 to a depth of 4,342 feet (1,320 m.) without encountering the cap, and on the southeast by the Rycade Oil Corporation's Houssiere Latreille No. 2, which encountered the cap at 3,395 feet (1,034 meters and a recent well which encountered the cap at ca. 2,717 feet (828 m.) in Block 6 in the SW. $\frac{1}{4}$ SW. $\frac{1}{4}$, Sec. 46.

The structure of the Jennings oil field was inferred by Harris on paleontological grounds to consist of a rather sharp, double-crested, structural dome, located about on the western 1,500 feet of the line between the Arnaudet and the Houssiere Latreille tracts. His inferences were drawn largely from the distribution of *Rangia johnsoni* in the wells. On the northwestern of the two crests, this fossil was found at a depth of 1,025 feet (307 m.), although 200 feet (60 m.) to the south, it was not encountered until below a depth of 1,940 feet (582 m.). On the basis of this distribution Harris drew in structure contours showing a dip of about 80 degrees on the south side, and of 45 degrees on the north side. On the southeastern crest, the upper limit of *Rangia johnsoni* was 1,300 feet (390 m.), and on both the north and south sides of the crest, Harris gives structure contours showing a dip of about 75 degrees.

The presence of any such sharp doming in the subsurface beds at Jennings seems doubtful from the results of subsurface correlation, from the structure of the other domes, and from a priori reasoning. Graphic sections, with closely spaced wells, were drawn up by the writers as follows: a north-south section (Plate 6) along the west line of the Arnaudet and Houssiere Latreille tracts; two east-west, a north-south, and a northwest-southeast section in the west 40-acre lot of the Houssiere Latreille tract, and an east-west section along the south line of Section 48 (Crowley Oil and Mineral Company's lease). The best section that could be drawn east-west through the location of the suspected structural crests was fragmentary, and unsatisfactory. Although lithologic well-to-well correlation of graphic logs is rather unsatisfactory as a rule in the Gulf Coast, and is not to be given implicit credence, fairly satisfactory correlation was possible on all of these sections except the one through structural crests reported by Harris. No key bed is present that can be traced with confidence completely across any one of the sections, but there are several massive sands, especially in the top of the predominantly clayey zone extending from 1,000 feet (300 m.) downward and in the main productive zone. Moderate doming of a magnitude of 300 to 500 feet (90–150 m.) seems to be indicated by the correlation of the wells on these sections. The crest of the dome coincides approximately with the two crests reported by Harris and the doming extends at least to the edges of the field. The dip shown by the top of the cap checks the moderate doming shown by the correlation of the beds above it. From the Producers Oil Company's Houssiere Latreille No. 74, to the Rycade Oil Corporation's No. 1, the slope of the top of the cap is 26 in 100 and from the latter well to the Producers Oil Company's No. 101, the slope is about 16 in 100. No data are available in regard to the cap rock in the area covered by the two crests of the dome found by Harris, but as the wells in that area produced from depth of 1,700 to 1,900 feet (510–570 m.), the cap rock if present cannot be less than 1,900 feet (570 m.) below the surface. The Producers Oil Company's Houssiere Latreille No. 74, however, is immediately at the south edge of the northwestern crest, and the rather moderate gradient on the top of the cap is known to come directly to the edge of the sharp crest of Harris. Although it has not been demonstrated that structures similar to those of Harris are not present, no such fold is known on the other Gulf Coast salt domes. The salt cores themselves have equally steep dips on their flanks, and in some cases the edges of the lateral beds have been dragged up by the salt until they have similar dips, but in no case is such sharp doming known to exist in the Tertiary sediments by themselves. If the competence of unconsolidated sands and clays is considered, it is questionable whether it would be possible for a frustrate cone of such sediments, 1,500 feet across the base and a 1,000 feet high, to be intruded into overlying sediments. If there should be a tendency for any such intrusion of any such cone of these sediments, the latter should tend to yield, rather than transmit the thrust rigidly, unless either the resistance to the intrusion were very slight, or the internal mechanics of the intrusion were the same as in the intrusion of a salt

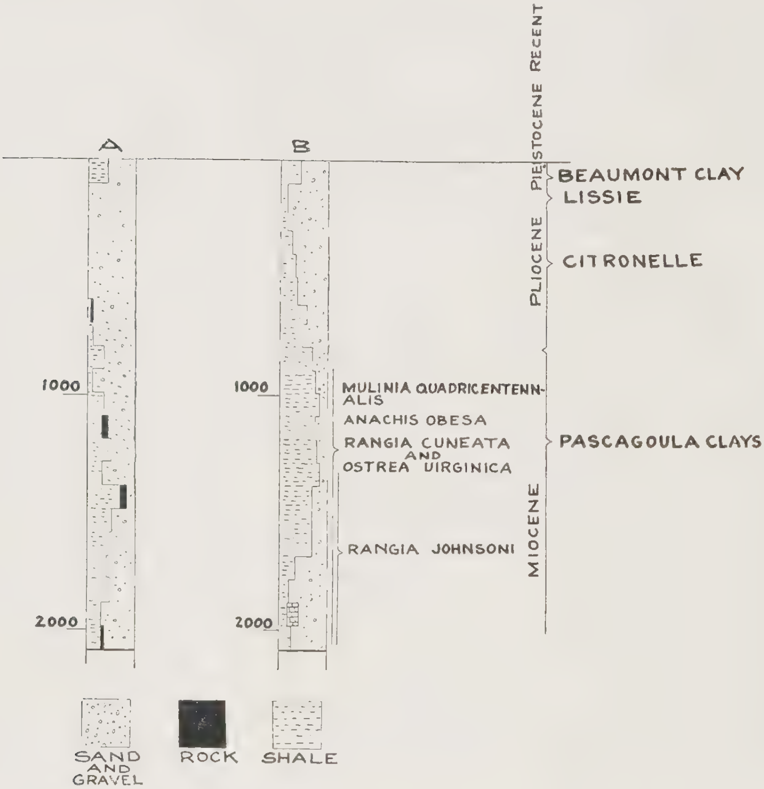

FIG. 3.—Graphic composite logs: (*A*) At edges of field (Crowley O. & M. Co. Nos. 20, 21, 22, and 23. Gulf Ref. Co.'s Clement Nos. 27, and 28, and Prod. O. Co.'s Houssiere Latreille No. 10). (*B*) At center of field (Prod. Oil. Co. Houssiere Latreille Nos. 1, 8, and 9; Teche Oil Co. Latreille No. 1, and Crowley Oil & M. Co.'s Houssiere Latreille No. 15).

dome. Neither of those special conditions, however, can be called upon to explain the situation at Jennings.

STRATIGRAPHY

The section in the center of the Jennings field (Fig. 3) is shown in the following tabular summary:

GEOLOGIC SECTION IN THE CENTER OF THE JENNINGS FIELD

	Feet	Meters
Predominating clay	0 – 60	0–18±
Predominating sand with some gravel and clay	60±–850±	18±–255±
Clay 70 per cent; sand 30 per cent	850±–1,750±	255±–525±
Clay 30 per cent; sand 70 per cent	1,750±2,000±	525±–600±
Limestone cap	2,000	2,000

The range of the fossils in the central part of the field is given by Harris as follows:

DISTRIBUTION OF FOSSILS IN THE CENTRAL PART OF THE JENNINGS FIELD

	Feet	Meters
Mulinia quadricentennalis	1,100	330
Anachis obesa		
Rangia cuneata and *Ostrea virginica?*	900–2,000	270–600
Rangia johnsoni and *Amnicola* sp.	1,300–2,000	390–600
Mulinia quadricentennalis Cerithium sp.	1,850	555
Mulinia quadricentennalis	200	600

The section on the edge of the field is as follows:

GEOLOGIC SECTION ON THE EDGE OF THE JENNINGS FIELD

	Feet	Meters
Predominantly clay	0 – 90±	0– 27±
Predominantly sand with some gravel and clay	90±–1,100±	27±–330±
Clay, about 70 per cent and sand, 30 per cent	1,100±–2,800±	330±–840±

In the only deep well drilled close in to the field, the Coastal Oil and Fuel Company's McDaniel No. 86, the section below 2,800 feet was as follows:

RECORD OF LOWER PART OF DEEP WELL NEAR JENNINGS FIELD

	Feet	Meters
Sand and rock	2,822–2,928	654– 890
Sand with thin beds clay	2,928–3,043	890– 925
Sand	3,043–3,182	925– 967
Sand with thin beds of clay	3,182–3,476	967–1,057
Sand	3,476–3,578	1,057–1,088
Sand and clay	3,578–3,856	1,088–1,172
Clay with some sand	3,856–4,181	1,172–1,271
Sand and clay	4,181–4,342	1,271–1,320

The conventional, normal stratigraphic section for southern Louisiana is as follows:

NORMAL STRATIGRAPHIC SECTION FOR SOUTHERN LOUISIANA

	Feet	Meters
Pleistocene:		
Beaumont. Clays and sands, and loess Lissie. Sands and gravels	1,500	455
(Unconformity)		
Pliocene:[1]		
Citronelle. Non-marine, yellow and red sands and clays; gray where unweathered	50–400	15–120
(Unconformity)		
Miocene:[1]		
Pascagoula. Marine in part, blue, green and gray clays, locally calcareous, some layers of sand	250–400	75–140
(Unconformity)		
Oligocene:[1]		
Hattiesburg. Non-marine, blue and gray clay, some beds calcareous, thin beds of sand and sandstone.	300–350	90–105
Catahoula. Non-marine, gray sands, sandstones, fine conglomerates, clays	600–800	180–240
Eocene:[2]		
Jackson. Marine-gray sands and dark calcareous clays	100–160	30– 50
Yegua. Palustrine-gypsiferous sands and clays with lignite	400–800	120–240

That this conventional section is not readily applicable at Pine Prairie is shown by the fact that here the thickness of the section above the Catahoula is at least 3,500 feet (1,050 m.), and is probably over 4,500 feet (1,400 m.) instead of 1,400 feet (420 m.) according to the maximum figures of the conventional section. On the basis of lithology, the following correlation of the section at Jennings is possible:

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[1] After G. C. Matson, *U.S.G.S. Prof. Paper No. 98-L*, p. 172.

[2] After E. T. Dumble, "Geology of East Texas," *Univ. of Texas Bull. No. 1869*, 1920, chapter v.

Lithologic Correlation of the Section at Jennings

	Feet	Meters
Clay zone, Beaumont clay	0– 90	0– 27
Sand zone, Lissie and Citronelle	90–1,100	27–330
Clay zone, Mainly Pascagoula (Miocene), possibly with some Citronelle (Pliocene) at the top and some Hattiesburg (Oligocene) at the base	1,100–2,800	330–840
Sand zone, Catahoula	2,800–?	(850)
Sand and clay zone, (?) Jackson	?–4,342	(1,320)

On the basis of megascopic fossils, Harris believed that the upper 2,000 feet, or possibly more of the section on the edge of the dome is Quaternary, and the beds immediately below, Miocene. Within the past three years a very considerable advance in the knowledge of Gulf Coast stratigraphy through micropaleontology has been made. However on examination of the samples from the Rycade Oil Corporation's Houssiere Latreille Nos. 1 and 2 showed no fossils. No examination of the samples from any other Jennings well has been made.

OIL AND GAS

INDICATIONS

The indications which led to the drilling at Jennings were the mound, and the gas seeps that had been long known about 600 feet north of the site of the first well. In these indications, the early pioneers saw all the earmarks of another Spindletop, but quickly discovered that the mound did not indicate the position of the oil. Within recent years, paraffin dirt has been recognized on the Arnaudet and Clement tracts. Sour dirt and oil seeps have not been reported.

Gas.—Not much gas was found. The upper 600 to 800 feet of the overlying section consisting of sands, gravels, and sandy clays, do not afford the necessary impervious strata for the accumulation of large amount of gas. The gas in only a few cases is found above the oil-bearing member. This fact is in large measure responsible for the rather low initial production and very low rate of decline of wells which ultimately produced very large amounts of oil. The gas at Jennings appears to have the same poisonous, hydrogen sulphide content, characteristic of the gas at Batson and Spindletop.

Oil.—The oil field covers an irregularly elliptical area of about 300 acres centering around the northwest corner of the Houssiere Latreille tract, Section 47 (Plate 7). Nine-tenths of the production came from a circular area of about 120 acres in the northwest corner of the Houssiere Latreille tract, the west end of the Arnaudet tract, the eastern edge of Section 46, and the southwest corner of Section 48.

The depth of the oil "sands" ranges from 110 to 2,400 feet (33–730 m.). A small production of heavy black oil from small pumpers was obtained in the early days from depths of 110 to 150 feet (33–45 m.) on the south side of the field. The main productive zone was a series of fine, unconsolidated sands between the depths of 1,700 and 1,900 feet (515 and 575 m.). Shows of oil are reported not uncommonly to have been found at depths of around 1,000 feet (300 m.) but no commercial production was obtained from that depth. A few wells produced from depths between 1,600 and 1,700 feet (485 and 515 m.) and a number from depths of 1,900 to 2,100 feet (575–635 m.). Of the latter wells, a few were very good producers, as for example:

Crowley O. and M. Company No. 1, 4,000 bbls. (555 tons) from 1,915–1,965 feet (574–596 meters)
Heywood O. Company Crowley No. 1, 8,000 bbls. (1,110 tons) from 1,909–1,962 feet (572–595 meters)
Producers O. Company Clement No. 4, 5,000 bbls. (690 tons) from 1,916–1,966 feet (574–596 meters)

On the west side of the field productive sands were found down to depths of 2,400 feet (730 m.). No production was obtained from the cap rock. Deep lateral production has not been found, but the possibilities have not been well tested. On the north side of the field, the Coastal O. and F. company's No. 86 was drilled to 4,342 feet (1,319 m.) without obtaining production, and on the southeast side of the field, the Rycade Oil Corporation's Houssiere Latreille No. 2 is drilled to 3,489 feet (1,063 m.) without having obtained production.

Productive zones can be traced vaguely for considerable distance from well to well. It is difficult to trace individual "sands" even across short distances. A "sand," in many cases, seems to have been a portion of a much larger mass of barren sand from which it is not logged as having been cut off by any partings. The thickness of the sands is difficult of determination, but seems to range from 10 to 150 feet (3 to 45 m.), averaging 40 to 60 feet (12 to 18 m.).

PRODUCTION

The total production of the Jennings field for the twenty-two years, 1902 to 1923, inclusive, has been approximately 46 million barrels (6,388,000 tons). The rapid rise, and somewhat gradual decline of production compares most favorably with Spindletop. The maximum annual production of the Jennings field, 9 million barrels ($1\frac{1}{4}$ million tons) in 1906, however, is only about half of the maximum annual production of the Spindletop field, 17 million barrels ($2\frac{1}{3}$ million tons) in 1902. The production of the Jennings field is shown graphically in Fig. 6.

With the exception of Humble and West Columbia, Jennings has had more big gushers than any other field of the Gulf Coast. The number and size of the gushers were as follows:

Gushers in the Jennings Field

Barrels	Tons	No. of Wells
4,000	550 per day I.P.	12
5,000	700	9
6,000	825	5
7,000	950	7
8,000	1,110	4
10,000	1,400	2
15,000	2,100	1
20,000–60,000	2,700–8,000	2
Very large but record lost		3
Total		45 wells over 4,000 bbls. per day initial production

Two wells in the Jennings field were distinguished by their large, steady output; Bass and Benkenstein No. 1 produced $1\frac{1}{2}$ million

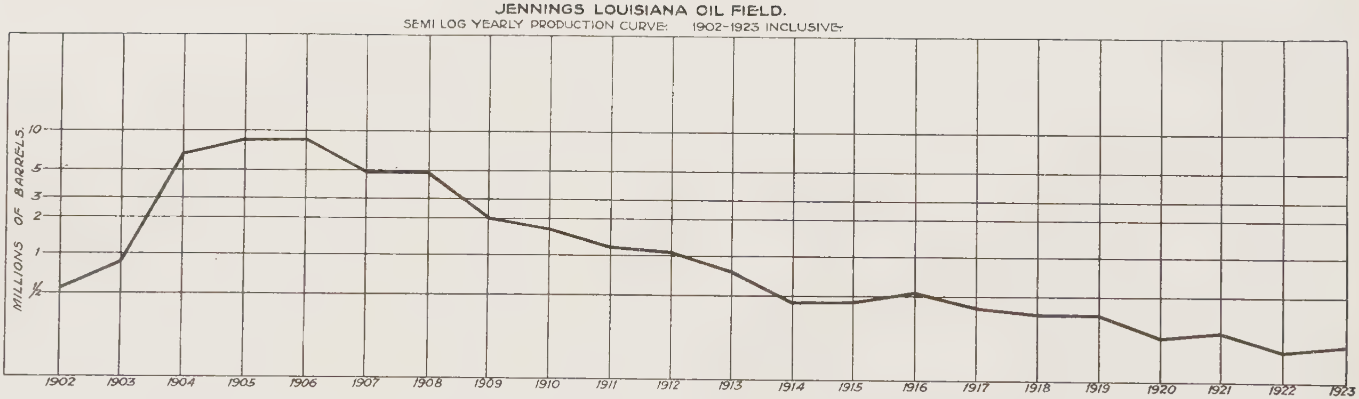

FIG. 4.—Semi-log curve of yearly production for Jennings Field

barrels (208,000 tons) of oil in 145 days from September 8 to January 31; and the Wilkens No. 2 produced one million barrels (138,000 tons) of oil in 82 days from November 20 to February 10 and made a total of 2½ million barrels (347,200 tons) before it finally quit producing. The Abrams No. 1 of West Columbia probably holds the record for the amount of oil produced in three months, but either the Bass and Benkenstein No. 1 or the Wilkens No. 2 probably holds the record for long continued high production, as both these wells had a daily production of less than 13,000 barrels (1,700 tons).

The per acre production of the Jennings field is one of the highest for any of the Gulf Coast fields (Figs. 4–6). The per acre production of the field as a whole is 153,000 barrels (21,000 tons). But as over 80 per cent, and probably 90 per cent of the production came from an area of about 120 acres, the per acre production of the main field is of the order of 300,000 to 340,000 barrels (41,000–47,000 tons).

Table I shows the variation in the temperature (?) and the gravity of the oil:

TABLE I

Temperature and Gravity of Jennings Field Oil

	Temperature		Gravity	Depth	
	F.	C.	Baumé	Feet	Meters
Gulf Production Co.					
Fee Simple No. 28	72	22	21	1545	470
Jennings Fee No. 2	80	27	23½	....	....
Syndicate Fee No. 29	80	27	20	....	....
Syndicate Fee No. 34	98	37	25½	2104	651
Jennings Clemont No. 12	72	22	21½	1575	479
Jennings Clemont No. 17	80	27	22	....	....
Jennings Clemont No. 16	68	20	23½	....	....
Arnaudet No. 14	70	21	21	....	....
Arnaudet No. 20	95	35	24½	....	....
Arnaudet No. 21	102	39	23½	1900	578
Morse No. 21	82	28	22½	....	....

These data are from gauger's observations. The low temperature looks suspicious, and it is probable that the three higher temperatures, 95°, 98°, and 102° C. are the most nearly correct. If the mean annual temperature of the ground at Jennings is taken as the same as the main annual free air temperature at Houston, the geothermal gradient is 58 feet per 1° F. (28.7 meters per 1° C.) for Arnaudet No. 21, and 73 feet per 1° F. (39.9 meters per 1° C.) for Syndicate

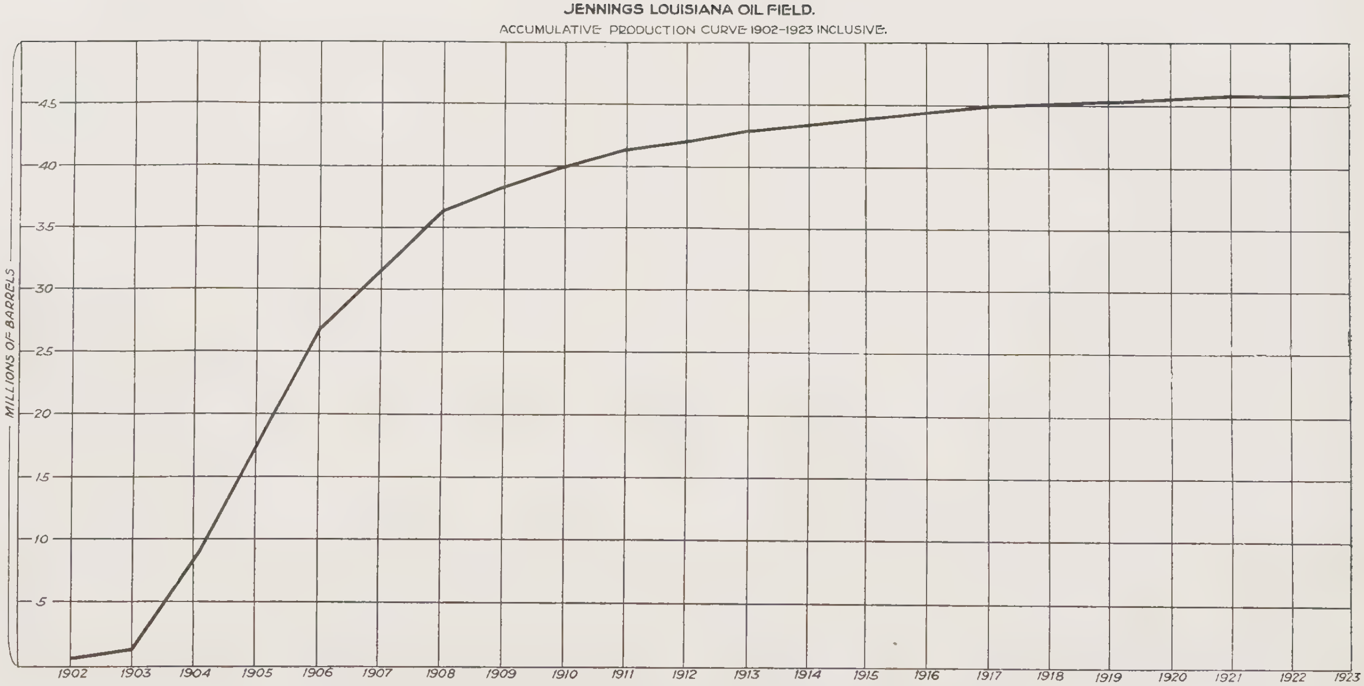

FIG. 5.—Curve of accumulative production for Jennings Field as a whole

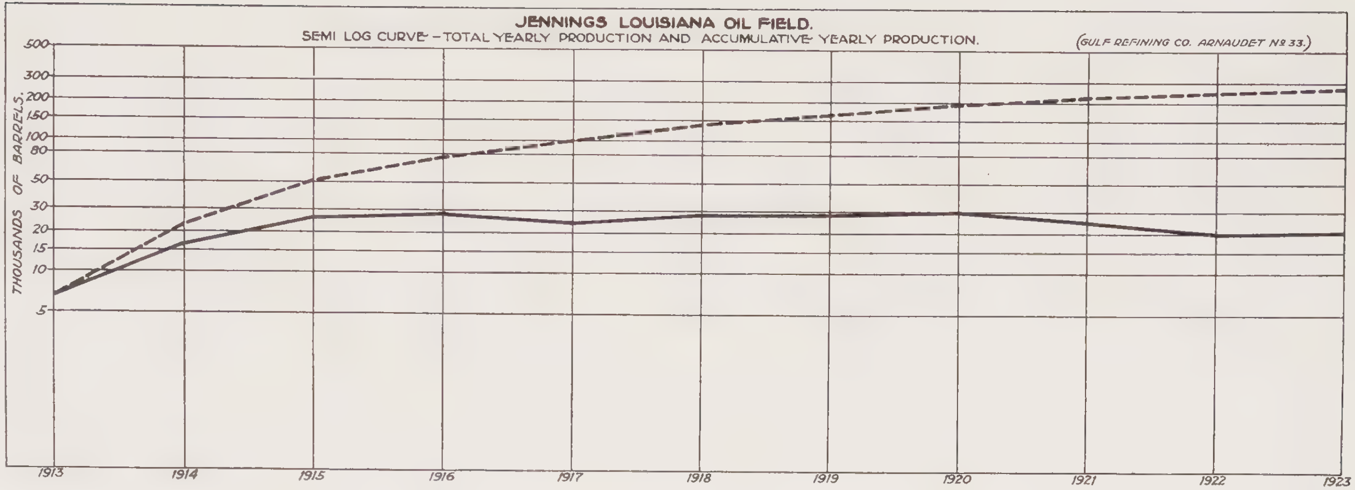

FIG. 6.—Semi-log curve of yearly and accumulative production for an individual well

Fee No. 34. This gradient is considerably higher than that at West Columbia, and is considerably lower than at Batson and Sour Lake.

The gravity of the oil shows a range of some 5½ degrees Baumé. A suggestive relation of gravity with depth is revealed, if the gravity is plotted with depth:

Distribution of Gravity of Jennings
Crude with Depth

Depth Feet	Meters	Gravity Baume
1,545	470	20.8
1,575	479	21.6
1,900	578	23.4
2,104	651	25.4

A similar increase of gravity with depth holds in an interesting manner at Orange over a vertical zone of 2,500 feet. There the gradient is much lower, about 250 feet per 1° Baumé in comparison with about 100 feet per 1° Baumé at Jennings.

FUTURE OF THE FIELD

The field at present is nearly dead. In 1922 there were 5 completions; of these, 3 were producers and 2 were dry. The production can be increased slightly by cleaning out, resetting, or redrilling old wells, and by drilling strippers to small sands that were passed up in the early days. But under the present-day technique of oil recovery, the old productive area is essentially exhausted. There is a possibility that deep, productive sands will be found. The results, however, of the Coastal Oil and Fuel Company's No. 86 on the north side of the dome and of the Rycade Oil Corporation's No. 2 on the southeast side do not look auspicious for the finding of deep, lateral production. But the deep, lateral sands have not been sufficiently tested to be entirely condemned.

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PINE PRAIRIE SALT DOME

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ABSTRACT

The Pine Prairie salt dome is a characteristic Gulf Coast salt dome, and is composed of a steep-sided, relatively flat-topped, pluglike salt core surmounted by a thimble-like cap of limestone and gypsum-anhydrite. The salt core is 1 mile in diameter and rises to within 520 feet of the surface. The limestone of the cap is exposed at the surface. The salt core and cap have been intruded into beds of Oligocene to Pliocene age. Commercial production has never been established. Four small producers were completed at a depth of about 1,300 feet on the west edge of the dome. Three later well located deep tests respectively on the northeast, southeast, and southwest sides of the dome were dry.

INTRODUCTION

Location.—The Pine Prairie salt dome is the northernmost of the Coastal group of Louisiana salt domes. It is in the southern central part of the state, in secs. 35 and 36, T. 3 S., R. I. W., 1 mile ($1\frac{1}{2}$ km.) west of Easton, a small lumber village in the center of Evangeline Parish. It is about 7 miles southwest of the village of Bayou Chicot, in what was formerly the northwest part of St. Landry Parish. It is reached by various lines to Alexandria, or by the Gulf Coast Lines to Eunice, and from either place by the Alexandria-Eunice branch of the Rock Island Railroad to Easton. Except in very wet periods, it can be reached readily by auto from either Alexandria or Lake Charles via the Pelican Highway to Oakdale, east across country to Pine Prairie village, and then south to the salt dome.

History.—The outcrop of the limestone on the southwest side of the salt dome was known to the early settlers; before the Civil War considerable lime was burned in rude kilns, the remains of which are still visible a little north of the saw mill and not far from the main quarry. About 1908, the dome was prospected by the Myles Mineral Company for limestone and salt, but no development was started.

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[1] Chief geologist, Rycade Oil Corp., Houston, Tex. Published by permission of the Rycade Oil Corp.

Harris is reported to have noticed that when heated the limestone from the lower quarry gave off a petroleum odor, and to have advised exploration for oil. The exploration was started in 1909, but the first wells were unsuccessful. In 1912, the Myles Mineral Company's Number 8, on the west side of the dome, came in flowing at an estimated rate of 1,000 barrels per day. Although the well quickly sanded up, its completion started a mild boom, and some seventeen wells were drilled in the following three years. Two of these wells were completed as small producers. None of the tests were deep. From 1915 to 1920, there was desultory drilling of shallow tests without success. In 1921, the Amerada Petroleum Corporation and the Louisiana Oil and Refining Company (Invincible Oil Corporation), in a joint test, drilled a deep dry hole on the northeast flank, and Duke *et al*. drilled a deep dry hole on the southwest flank. In the following year, the Louisiana Oil and Refining Company drilled a well into the southeast edge of the cap, and a deep dry hole a little farther southeast. At the present time there is no commercial production.

PHYSIOGRAPHY

Regional physiography.—The physiographic province in which the salt domes of Louisiana and Texas occur is the Gulf Coastal Plain. In southern Louisiana, and southeast Texas, this plain is composed of the Coastal Prairie, the Kisatchie Cuesta, other cuestas farther inland, and the Mississippi Valley and Delta (Fig. 1).

The Coastal Prairie is an almost featureless plain extending from the Gulf Coast about 80 miles inland. At its gulfward margin, it is characterized by extensive marshes, especially in Louisiana and the adjacent portion of Texas, and is broken by numerous broad, shallow bays. At its inland margin, the coastal marshy belt grades into a wide belt of prairie which comprises the main part of the Coastal Prairie, and which is practically treeless except along the streams and at its inland margin.

The Coastal Prairie is in extreme physiographic youth. Along the streams and their tributaries, in general, there is considerable dissection. The interstream areas are broad and show no well-defined drainage. The amount of the dissection increases inland, and near the inland margin, the topography locally is in late youth. The only relief which the Coastal Prairie has beyond that due to the erosion consists of:

1. Salt-dome mounds; mounds resulting from the upwarping of the prairie and rising to a maximum height of 200 feet above the general prairie level.

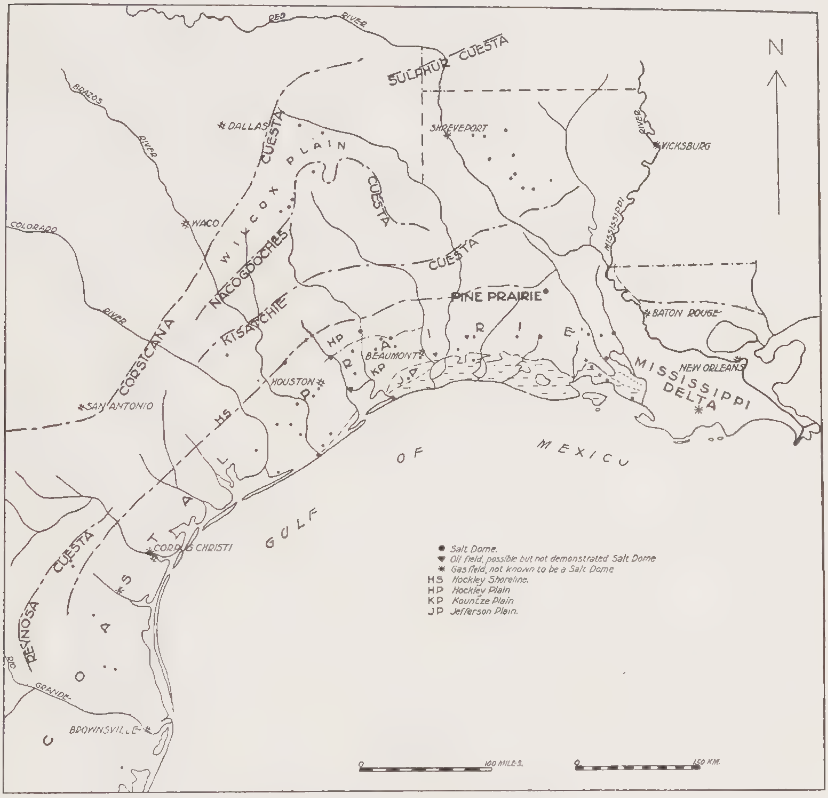

FIG. 1.—Physiographic map of the Texas-Louisiana salt-dome area. (In part after Deussen, Dumble, and Veatch.)

2. "Pimple" mounds and "blowout" holes; small, circular, sandy mounds with diameters of 20–30 feet (6–9 m.), and a rise of 1–4 feet (0.3–1.3 m.); and shallow, circular ponds of somewhat larger diameter. Contrary to the common lay opinion, they have no connection with oil, gas, or salt domes.
3. Prairie ridges; broad, low ridges extending for miles across the prairie.
4. Natural levees; in some cases abandoned.
5. Beach ridges; especially in the marshy prairie along the coast.

The Coastal Prairie is divided into several plains, marked at their landward edges by scarps, and is bounded at its inner margin by the Hockley shore line. In Louisiana and farther east, four terraces have been recognized: in order of decreasing age, the St. Elmo, the Port Hickey, the Hammond, and the Pensacola.[1] The St. Elmo terrace, apparently contemporaneous with the crystalline gravel at Natchez, but older than the great loess deposits of the east side of the Mississippi, is regarded by Matson as sub-Aftonion in age. As the Port Hickey terrace is apparently younger than the principal loess deposits of the east side of the Mississippi, the St. Elmo terrace would be pre-Iowan in age, and the Port Hickey terrace of post-Iowan age. The latter terrace is covered by a loesslike silt that may be of Wisconsin age, and in that case would itself be of Wisconsin age. The lower terraces are younger than the Wisconsin drift.

In southeast Texas, there are at least three plains: the Hockley Plain, with its inner margin well marked by the Hockley shore line through the Hockley salt dome; the Kountze Plain, which is especially well developed near Kountze; and the Jefferson Plain, which is best developed in southern Jefferson County. The Hockley Plain lies between elevations of 110–50 feet (33–45 m.) in Hardin County, and 125–75 feet (37–52 m.) in western Harris County. The Kountze Plain lies between elevations of 25–80 feet (8–25 m.) in Jefferson and Hardin counties, and between 30–90 feet (9–27 m.) in Harris and Galveston counties, and in the latter two counties, it extends nearly to the coast. The Jefferson Plain has an elevation of less than 15 feet (5 m.). The Hockley shore line is a rise of 40 feet (12 m.) in 1 mile, which contrasts strongly with the very uniform slope of the Coastal Prairie of 3 feet (1 m.) to the mile. This shore line crosses the Dallas-Beaumont branch of the Southern Pacific Lines just south of Seneca, the Houston, East, and West Texas division of the Southern Pacific lines just north of Wescott, and the Houston-Palestine division of the International and Great Northern Railroad just south of Conroe.

The Kountze shore line between the Hockley and Kountze plains is most conspicuous between Kountze and Saratoga in Hardin

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[1] G. C. Matson, *U. S. G. S. Prof. Paper 98-L* (1916), pp. 189–90.

County, and is recognizable but indistinct in Harris County, southwestward from Humble.

The Jefferson shore line between the Kountze and Jefferson plains crosses the center of Jefferson County, near the western edge of the county, bends southwestward, and in Galveston County is only some 10 miles back from the coast. As the Loxley Plain, the youngest of the Pliocene plains, is represented on the east border of Texas, according to Matson, by the top of hills that rise 180–220 feet (56–68 m.) above sea-level, the Hockley shore line is the equivalent of the scarp which marks the seaward edge of the Loxley Plain, and the Hockley Plain is the equivalent of the next lower plain, the St. Elmo Plain. The Jefferson Plain may be the equivalent of the Pensacola Plain, and the Kountze Plain may be the equivalent of the Port Hickey and Hammond plains, but the data for exact correlation are not at hand.

In the area around the Pine Prairie salt dome, there is a broad upland level with an elevation above sea-level of 95–110 feet (29–33 m.), and a bottom land with an elevation of 50–60 feet (15–18 m.) above sea-level. The area has suffered much more erosion than the prairie nearer the coast. Only remnants of the upland level are left in the area around the Pine Prairie dome. The general region is flatly rolling with fairly broad bottom lands along the streams. By comparison of the elevation and position of this area with Matson's profiles, the upland level seems perhaps to be a part of the Port Hickey (Pleistocene) terrace, and the bottom lands to correspond to the Hammond terrace. To the south of the Pine Prairie dome, most of the prairie is open, but in the immediate vicinity, and to the north of the dome, most of the prairie is wooded.

Physiography of the dome.—The characteristic American salt dome consists of: (1) a circular pluglike core of rock salt; (2) beds dipping quaquaversally away from the salt core; and in some cases(3) a cap of rock mantling the top of the salt core; and (4) a topographic mound above the salt core. The salt-dome mound tends to have the general shape of an inverted tin wash-basin with or without a central depression.

The Pine Prairie salt-dome mound (Fig. 2) is a subcircular horseshoe-shaped mound roughly 6,000 feet (1.8 km.) in diameter and rising 60–75 feet (18–23 m.) above the general level of the bottom lands which surround it on the south, west, and north. Mapping carried well out from the dome shows, however, that these surrounding lands standing at levels of 60–70 feet (18–21 m.) above sea-level are merely the bottom lands of Nez Pique Bayou and Caney Branch, and that there is also the upland standing at a level of 75–110 feet (23–33 m.) above sea-level. The rise of the mound above this upland level, which seems to be the correct measure of the salt-dome mound proper, is 15–20 feet (5–6 m.).

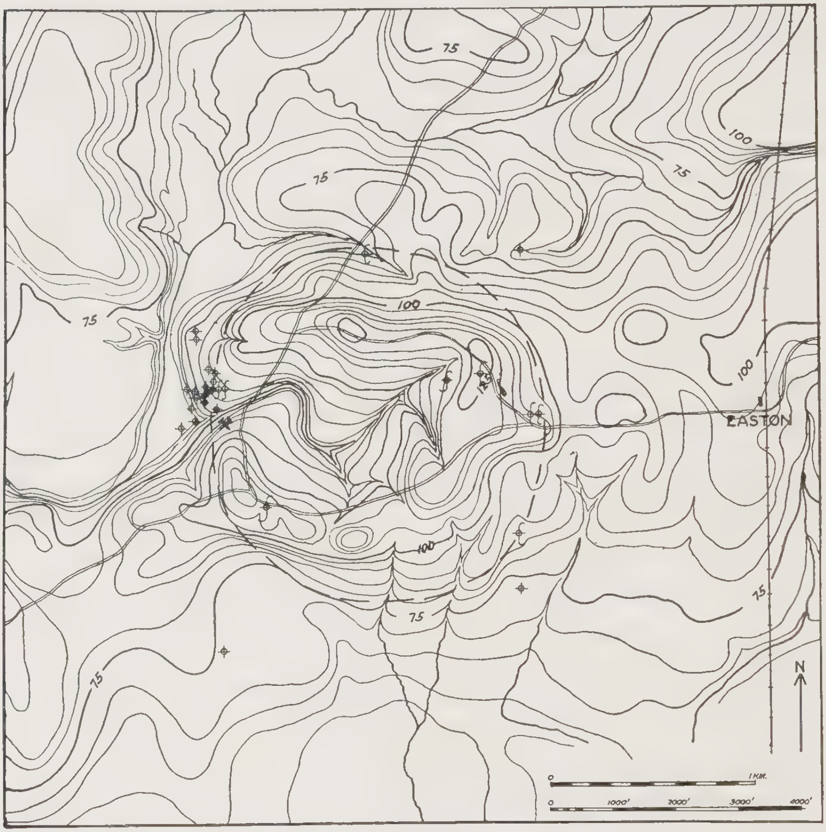

FIG. 2.—Topographic map of the Pine Prairie salt dome. (By Amerada Pet. Corp., Van K. Baker—topographer; topography slightly redrawn by D. C. Barton—datum mean sea-level; contour interval, 5 feet.)

Although the central basin may be entirely erosional in origin, it is more probably a central depression of the type characteristic of the "central depression type" of salt-dome mounds. The basin has somewhat the shape of a shallow wash-basin with gently sloping, graded sides and a broad, flat, central floor. The west rim is breached by a small brook which heads on the inside of the east rim. This brook flows in a V-shaped brook valley, a few feet deep, and 10–20 feet wide. The brook seems incompetent to have carved such a basin, but there is a bare possibility that the basin is the result of a former period of erosion, so ancient that the sandy hill-slopes have had a chance to become completely graded, and that recent rejuvenation has resulted in the erosion of the modern brook valleys.

In general plan, the Pine Prairie mound seems to be similar to the Blue Ridge mound.

GEOLOGY

Surface.—The surface beds of this general region are sands and sandy clays which belong to that Pleistocene belt of sands which lies inland from the more clayey Beaumont clay to the south, and overlaps the Citronelle formation to the north (Fig. 3). This belt has been included by some writers in the Lafayette, together with much of the underlying Citronelle formation. This belt in Texas was placed by Deussen in the Lissie together with much of the Citronelle Formation; and by Hayes and Kennedy and by Fenneman it was correlated with McGee's Columbia formation, to which the Lissie is now more or less restricted.

The surface beds on the Pine Prairie salt dome consist of sands and sandy clays, and of limestones piercing the sands and clays. Lithologically, the sands and clays on the dome show no marked differences from those of the surrounding region, except possibly in being very slightly more sandy. But as transitions from belts of sandy soil to those of sandy clay are not uncommon, the apparently greater sandiness of the mound is not necessarily of significance.

Limestone is exposed at two points in the southwest quadrant of the dome. One exposure is in a small pit on the north side of the road and some 500 feet (160 m.) east of the mill. This exposure consists of a little rotten limestone and a few small bowlders of sounder limestone. The other exposure is about 1,200 feet (400 m.) north of the mill on the west side of the road, and just south of the bridge over the brook. On only three other coastal domes, Falfurrias, Damon Mound, and Hockley, is solid rock exposed at the surface.

The area in which the limestone comes near the surface is essentially that of the southwest quadrant of the dome. On the hill that forms the rim in that quadrant, on the south end of the hill to the north, and the southwest portion of the central depression, the limestone is reported to have been encountered by shallow tests at depths of 20–50 feet (6–16 m.). Elsewhere over the dome, the limestone lies at greater depths.

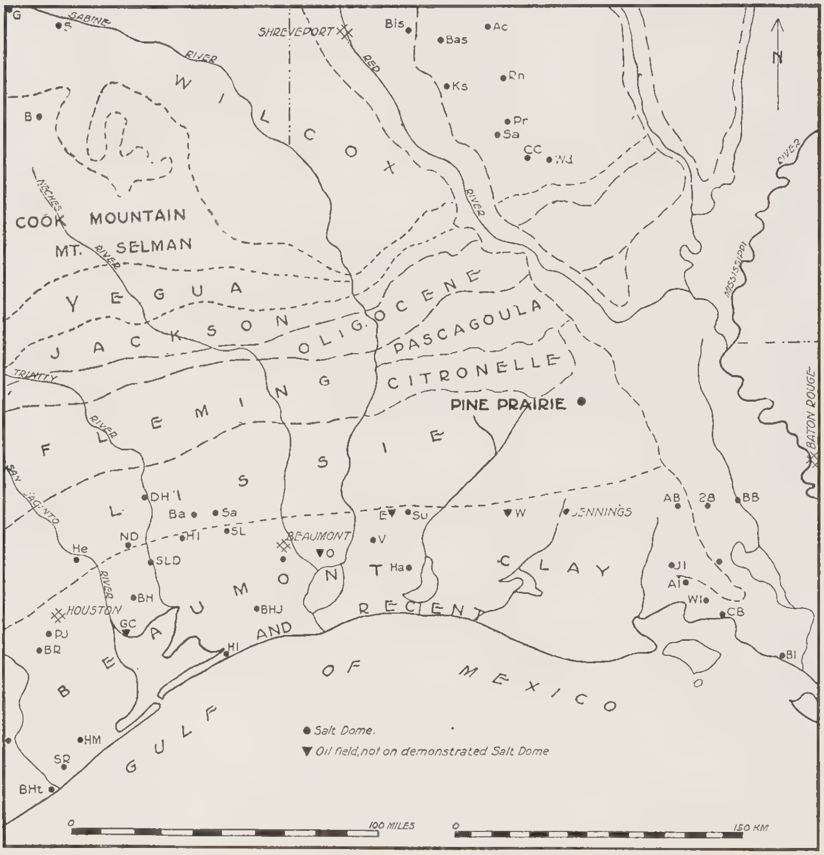

FIG. 3.—Geologic map of Louisiana and East Texas. (Largely after Deussen, Dumble, Harris, Matson, and Veatch.)

The thickness of the limestone is shown by wells to be 200–400 feet (160–320 m.). From the well logs it is not quite certain whether or not the limestone exposed at the surface is continuous with the main cap rock or is an upper lense.

Banding shown by the limestone of the lower quarry has dips of 25–30 degrees to the southwest. As the blocks on which the dips have to be taken are not firmly in place, these dip readings are only approximate. Diamond-drill cores of cap rock from a test near the mill on the crest of the hill in the southwest quadrant are said to have shown dips of 30°. Although the limestone exposed in the upper quarry is very doubtfully in place, the banding seems also to show a southwesterly dip.

Subsurface.—The wells drilled show the presence below the surface of a characteristic salt dome, composed of a pluglike central core of rock salt capped by a thimble-like mass of cap rock.

The cap rock is flat topped and has steep sides (Fig. 4). On the top of the dome, Myles Mineral Company's wells Nos. 1, 2, and 3 went into the salt respectively at 405 feet (122½ m.), 405 feet, and 420 feet (127½ m.) below sea-level, and 520 feet (157½ m.), 516 feet (156½ m.), 520 feet (157½ m.) below the surface. The location of these wells was as follows: No. 1 about 1,000 feet (300 m.) in from the southeast edge of the salt table; No. 2 on the west edge of the salt table; No. 3 in the center of the northeast quadrant of the dome, about 1,500 feet (450 m.) in from the edge of the salt table. The dip of the flank of the salt core is known directly only on the west. There the Myles Mineral Company's No. 6, which was 50 feet (16 m.) west of No. 2, went into salt at 685 feet (207½ m.) below sea-level, or 265 feet (80 m.) deeper; and well No. 8, 80 feet (24 m.) west of No. 6, went to 1,135 feet (343 m.) below sea-level without encountering salt. On the northeast, southeast, and southwest, wells drilled to 3,879 feet (1,175 m.), 4,100 feet (1,240 m.), 4,384 feet (1,328 m.) below the surface, respectively, show that to depths of around 4,000 feet (1,200 m.) the mean slope of the edge of the salt is greater than 4½ in 1.

The salt core is approximately circular in plan (Fig. 5). It is delimited by the previously mentioned wells, and by Price's Crowell and Spencer well at NW. cor. Sec. 36, the two Price wells at the cen-

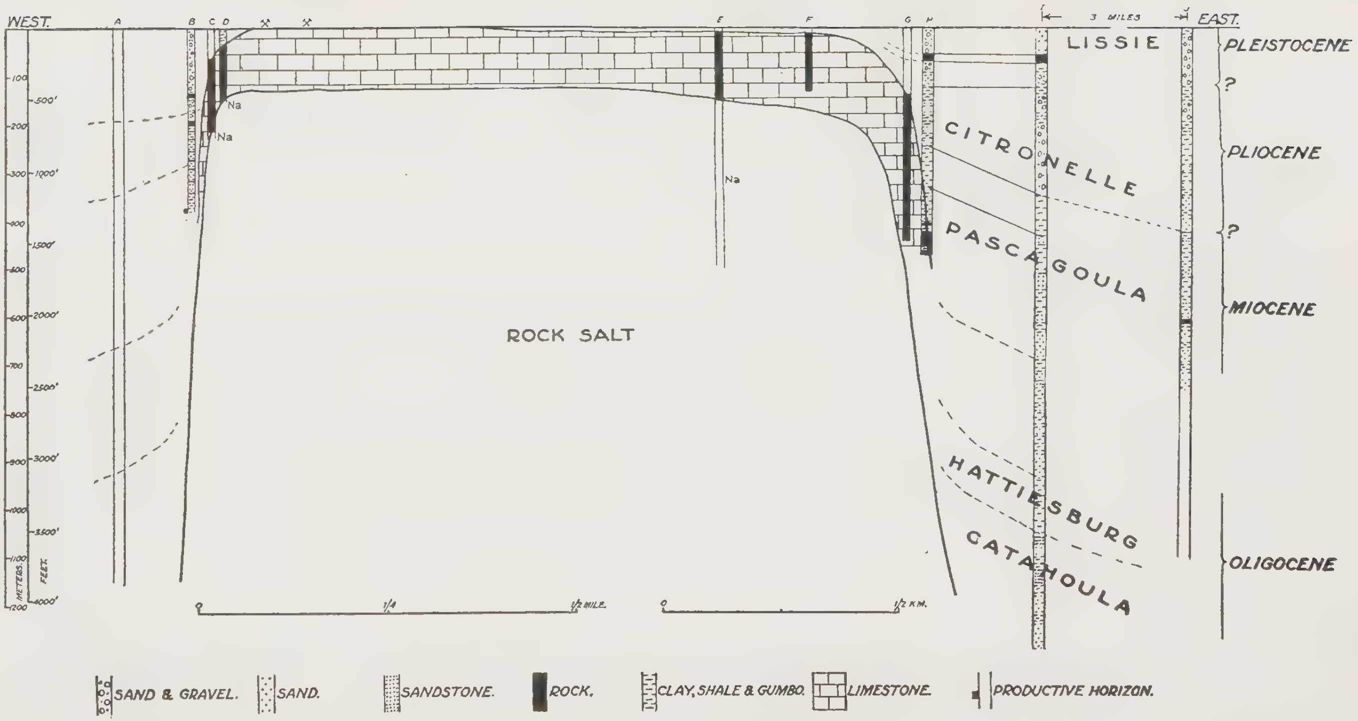

FIG. 4.—West-east cross-section across the Pine Prairie salt dome
Vertical scale = Horizontal scale

A = Duke *et al.*'s Le Danois No. 1
B = Myle's Mineral Co.'s No. 8
C = M. M. Co.'s No. 6
D = M. M. Co.'s No. 2
E = M. M. Co.'s No. 3
F = M. M. Co.'s No. 0
G = Price-Cannon's Guillory No. 1
H = La. O. & R. Co's–Vidrine No. 1
I = La. O. & R. Co.'s Gournay No. 1
J = Pine Prairie Realty Co's No. 1 (3 mi. N.-NE. of the dome)

ter of Sec. 36, and the Louisiana Oil and Refining Company's Vidrine well in the SE. cor. SW. ¼ of Sec. 36, all of which had cap rock at depths of over 1,000 feet (300 m.).

The cap seems to be a thimble-like mass of limestone and gypsum (anhydrite?) mantling the salt core. The limestone of the cap, or perhaps of an upper lense of the cap, comes to the surface in the southwest quadrant of the dome. Seven hundred feet south of the upper quarry, the Myles Mineral Company's No. 1 encountered the cap at a depth of 115 feet (35 m.) below sea-level. On the west edge of the dome, the same company's No. 2 encountered it at a depth of 30 feet (9 m.) below sea-level. In the middle of the northeast quad-

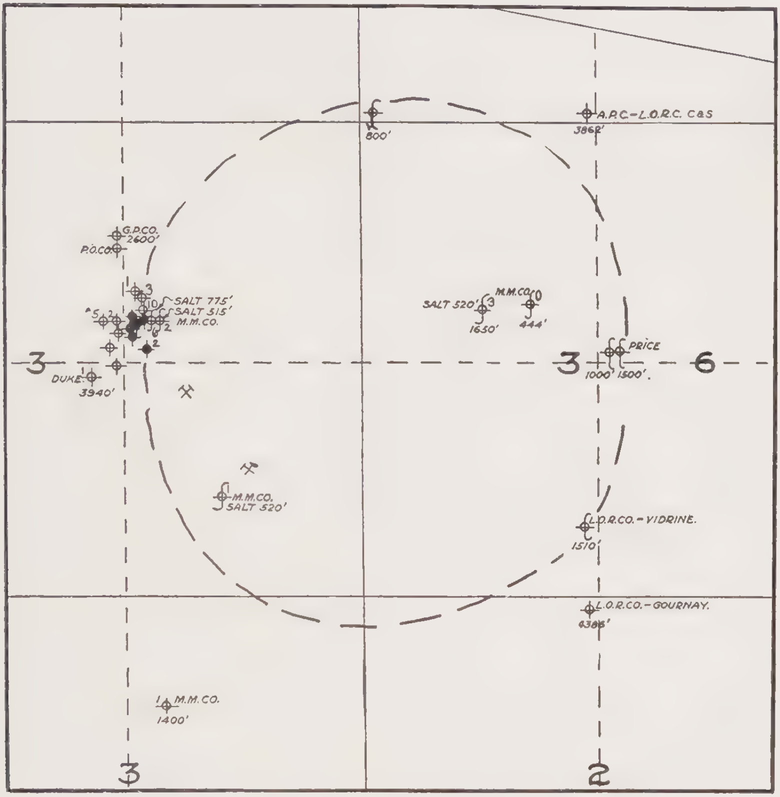

FIG. 5.—Index map to wells at Pine Prairie salt dome

rant, the same company's Nos. 0 and 3 encountered it slightly below sea-level. On the north edge of the dome, Price's Crowell and Spencer No. 1, was abandoned in it at a depth of 730 feet (221 m.) below sea-level. The depth of the top of the cap, however, is not available. On the east edge of the dome, Price's two wells encountered the cap at a depth of around 325 feet (100 m.) below sea-level; one of them was abandoned at around 900 feet (275 m.) and the other at around 1,400 feet (420 m.) below sea-level. On the southeast edge of the dome, the Louisiana Oil and Refining Company's Vidrine No. 1 encountered the cap at 1,380 feet (418 m.), and was abandoned in it at 1,510 feet (457½ m.) below sea-level.

The thickness of the cap on top of the dome is 200–400 feet (160–320 m.). In some of the edge wells it has an apparent thickness up to 1,000 feet (350 m.). This great apparent thickness is probably due to the fact that the limestone is dipping at a high angle.

The cap rock is composed of limestone and gypsum (anhydrite?), the relative proportion between the two being indeterminable. The cap exposed at the surface is limestone, and the impression gained from the accounts of the Myles Mineral Company wells is that the rock penetrated by them was mostly limestone. Some definite gypsum was encountered in them, and from the account of Mr. P. K. Kelly, of the Union Sulphur Company, the rock in the Price well on the east flank of the dome was entirely gypsum (anhydrite?). Sulphur-bearing rock was encountered in the Myles Mineral Company's wells Nos. 1 and 2. In a fishing job on the latter well, nearly a gallon of pure sulphur was brought up, some of it in lumps of pure sulphur half the size of a hen's egg and the rest of it in lumps of half-sulphur and half-limestone and gypsum.

Surrounding the salt core and the cap are sediments that probably dip quaquaversally away from the salt core and the cap. But the wells of which accurate logs are available are so scattered, and lithologic correlation between wells at a distance is so uncertain, that it is impossible to determine the dip at Pine Prairie, or to contour any horizon.

Stratigraphy.—The normal stratigraphic section for this area as determined from a study of these formations to the north is as follows:

STRATIGRAPHIC SECTION IN VICINITY OF THE PINE PRAIRIE SALT DOME

Pleistocene		
Lissie	Sand and gravel	0–200 feet (0– 60 m.)
(Unconformity)		
Pliocene*	Non-marine	50–400 feet (15–120 m.)
Citron formation	Yellow and red sands and clays	50–400 feet (15–120 m.)
(Unconformity)	Gray where unweathered	
Miocene*	Marine in part, blue-green and gray clays locally calcareous Some layers of sand	250–450 feet (80–140 m.)
Pascagoula clay		
(Unconformity)		
Oligocene*		
Hattiesburg clay	Non-marine, blue and gray clay, some beds calcareous, thin beds of sand and sandstone	300–350 feet (20–105 m.)
Catahoula sandstone	Non-marine gray sands, sandstones, fine conglomerates, clays	600–800 feet (180–240 m.)
Eocene†		
Jackson	Marine gray sands and dark calcareous clays	100– 60 feet (30– 50 m.)
Yegua	Palustrine, gypsiferous sands and clays with lignite	400–800 feet (120–240 m.)
Nacogdoches Cook Mountain Mount Selman	Marine, green sands, glauconitic sands, sandstones and clays, green, black and yellow clays, brown and yellow sand	700–800 feet (210– 40 m.)

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* After G. C. Matson, *U. S. G. S. Prof. Paper 98 L* (1916), p. 172.

† After E. T. Dumble, "Geology of East Texas," *Univ. of Texas Bull. No. 1869* (1920), Chap. V.

The actual stratigraphic section at and around the Pine Prairie dome is poorly known. A Fleming Miocene fauna is reported by Kennedy[1] to have been obtained from a depth of 1,545 feet (468 m.) in the Pine Prairie Realty Company's well. In the Amerada Petroleum Corporation–Louisiana Oil and Refining Company's Crowell Spencer No. 1, "re-worked Cretaceous" (Miocene) was encountered from 1,272–986 feet (385–602 m.)[2] From 1,986 feet (602 m.) to the bottom of the hole, 3,879 feet (1,115 m.), there were no megascopic or microscopic fossils, and the micro-lithology did not allow a determination of the formations. On the basis of lithology, the upper 600 feet of the Pine Prairie Realty Company's well, and the upper 400 feet of the section in the wells immediately around the Pine Prairie dome, seem to be Citronelle and Lissie, and the zone of sand and rock, 3,600–900 feet in the Louisiana Oil and Refining Company's Gournay No. 1, and 3,500 feet in the Amerada Petroleum Corporation and Louisiana Oil and Refining Company's Crowell Spencer No. 1, seem to be Catahoula, but as part of the Oligocene is fairly fossiliferous, the Amerada Petroleum Corporation–Louisiana Oil and Refining Company's Crowell Spencer No. 1, abandoned at 3,879 feet (1,175 m.), seem not to have gone very far into the Oligocene. According to the conventional section based on the study of the surface outcrops, a well 4,000 feet deep at Pine Prairie should be well into or through the Cook Mountain formation. From our knowledge from other salt domes, the formations at a depth of 3,000–4,000 feet in the Amerada Petroleum Corporation–Louisiana Oil and Refining Company's Crowell Spencer No. 1 should be 2,000 feet above their normal stratigraphic position. The actual stratigraphic section at Pine Prairie shows, therefore, an enormous thickening of the Miocene-Pliocene over the thicknesses given in the conventional section.

ORIGIN OF THE DOME

A study of the literature on the German salt domes shows that they have been proved to be the result of plastic deformation and upthrust of the Zechstein sedimentary salt series. It is evident, also, that certain of the German domes are very similar to the American domes, and therefore it is probable that the American domes have been formed similarly. The sections available for the American domes show clearly that the salt has been intruded as an upthrust plug. The bare profile of the Pine Prairie salt core against the surrounding sediments is, of course, in itself suggestive of its intrusive character, but on account of the slight correlation that is possible, the upthrust of the lateral beds is only vaguely indicated.

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[1] W. Kennedy, *Bull. S. A. Pet. Geol.* (1917), p. 37.

[2] Determined by Miss Ellisor, geology department, Humble Oil and Refining Company.

AGE OF THE DOME

The salt must be older than Oligocene if it is an intruded portion of sedimentary salt series, as the salt cuts what seems to be the Catahoula sandstone. The date of the beginning of the upthrust of the salt is not determinable at Pine Prairie. At Damon Mound, an angular unconformity of some 15° between the Oligocene and the Miocene beds of the flank indicate that there had been marked upthrust of the Damon Mound salt core during or at the end of Oligocene times. Although it can be shown definitely that some of the domes have experienced little or no upthrust since early Pleistocene times, and others have experienced upthrust in very recent times, it is probable that most of the salt domes were started by the same pulse in the tectonic situation. It is likely, therefore, that the upthrust of the Pine Prairie salt core had started by Oligocene times. The presence of the salt-dome mound rising as a deformation form above a late Pleistocene surface indicates that the latest movement took place in or since late Pleistocene times.

ORIGIN OF THE CAP ROCK

Three major theories for the origin of the cap rock of salt domes have been proposed: (1) It is reconsolidated, residual material left behind in the solution of the top of the salt. (2) It is rock that was caught and pushed ahead of the rising salt column. (3) It was formed by reactions between the circulating waters of the country rock and the salt-dome waters.

In the light of the present knowledge of the cap at Pine Prairie, no one of these theories gives a very plausible theory of its origin.

The first theory is plausible in connection with the gypsum cap of the German domes, but seems inapplicable in this case; the $CaCO_3$ content of the rock salt of all domes, as far as known, is practically nil, and there is no known indication of the alteration of the limestone from gypsum. The apparent thimble-like form of the cap at Pine Prairie is more what would be expected if the cap were a secondary deposit rather than an uplifted block. Secondary deposition of lime is common as a cement in sandstones around the salt domes of the Gulf Coast. But if the cap were secondary, it seems impossible for it not to have included some of the sedimentary beds, especially the sandstones which originally rested against the salt. Such inclusions are not known at present. As there have been only a few wells through the cap, it is, of course, not well known. The cap may not extend down the flanks in the manner of the writer's interpretation of the situation, and the cap rock found on the flanks may be blocks broken off from the main mass and lagging along the edges of the upthrusting salt core. As a result of the study still in progress of the form and shape of the cap rocks of Gulf Coast salt domes and the relation of the cap rock to the salt core and to the surrounding sediments, the writer has come to the conclusion that in case of most of the salt domes the cap rock has been upthrust on top of the salt core into its present position, but he has come to no definite conclusion in regard to the ultimate origin of the cap rock. However, the theory of the secondary deposition does not seem so plausible to him as it formerly did.

OIL AND GAS

Indications.—The indications which led to the drilling were the presence of small, dark, asphaltic specks in the limestone of the lower quarry. Upon abrasion the limestone gives off a strong, fetid odor, and when heated it yields a strong odor of petroleum. No oil seeps, gas seeps, or paraffin dirt are known at or around the Pine Prairie dome. Gas seeps have been reported from Caney Branch, but as they are not large, or constant, they are probably marsh-gas seeps.

Exploitation.—Over thirty wells have been drilled; three of the tests went to depths below 3,000 feet (900 m.): the Amerada Petroleum Corporation–Louisiana Oil and Refining Company's Crowell Spencer No. 1, about 1,200 feet out from the dome on the northeast to 3,879 feet (1,175 m.); the Louisiana Oil and Refining Company's Gournay's No. 1, about 800 feet out from the dome on the southeast to 4,384 feet (1,328 m.); and Duke *et al.*'s No. 1 on the west to 4,100 feet (1,240 m.). Nine wells went into the salt or cap rock at shallow and moderate depths. Of the others, sixteen did not go below 1,300 feet (400 m.). Four wells were completed as so-called producers.

Production.—The oil that has been found thus far is within a small area on the west flank immediately adjacent to the dome. It is found in a sand 30 feet (9 m.) thick between 1,200 and 1,300 feet (370–400 m.). The sand bed is probably in the Pascagoula clay (Miocene).

Though for a short time oil was shipped from Pine Prairie, the production has never reached commercial magnitude. Myles Mineral Company's No. 8, the discovery well, came in with an initial production of one thousand barrels (139 tons) per day (estimated), but quickly sanded up. It pumped twelve to twenty barrels (1.7–28 tons) per day for about a year, and then, after standing for three years or four years, pumped six to thirty-five barrels (0.8–4.9 tons) per day for a year and a half. Wells Nos. 10 and 11 were of the same type. More recently Duke *et al.* completed a twenty-barrel (3 ton) well at a depth of 1,239 feet. The total production of the field to date has been around twenty thousand barrels (3,000 tons).

The oil is a thin, dark-brown oil with a gravity said to be around 28–32° Baumé.

ECONOMIC POSSIBILITIES OF THE DOME

The economic possibilities of the dome are:

1. Limestone for: (*a*) ballast—for railroads or roads; (*b*) lime—before the Civil War the limestone was burned for lime. It is said to have yielded a bluish lime; (*c*) building stone—it is very problematic whether the rock within available distance of the surface is of sufficiently good grade for building stone; (*d*) soda ash—Harris has suggested that the occurrence of the rather pure $CaCO_3$ in association with minable salt might make possible the commercial production of soda ash. The amount of the overburden is not definitely known but since it probably amounts at a mimimum of 30 feet (9 m.) of sand and 20–30 feet (6–9 m.) of rotten limestone, it is

probable that the overburden precludes commercial utilization of the rock.

2. Salt: The occurrence of massive rock salt at a depth of only 500 feet (160 m.) under a heavy cap of firm rock offers a favorable situation for salt-mining.

3. Sulphur: A small amount of native sulphur was found in the cap rock in two of the wells. There has been no thorough prospecting of the dome for sulphur.

4. Oil: The cap has been penetrated by a sufficient number of wells to show that commercial production will probably not be obtained from it.

On the west side, a small production of light oil can probably be obtained from around 1,200–300 feet near the dome. Better production than that which has been obtained in the past may be developed, but production of any considerable size is unlikely.

The lateral beds above 3,900 feet (1,180 m.) look unfavorable. The three deep tests, on the northeast, southeast, and the west, were carefully drilled with due attention to coring and should have picked up any oil sands if they were present. Since the Oligocene is one of the most important productive horizons on the Gulf Coast salt domes, there is a possibility for production in these beds from below 4,000 feet (1,200 m.).

REFERENCES

G. D. Harris, *Geol. Survey of Louisiana, Report of 1899*, pp. 61–62.
Ibid., Report of 1907, Bull. 7, (1908), p. 35, Plate XXX.
U. S. Geol. Survey Bull. 429 (1910), p. 21.
Wm. Kennedy, *Bull. S.W. Assoc. Pet. Geol.* Vol. I (1917) p. 37.
Data regarding the older history and wells is largely from H. M. Journee.

THE WELSH, LOUISIANA, OIL FIELD[1]

LYMAN C. REED[2]
Houston, Texas

ABSTRACT

The Welsh oil field seems probably to be of the Goose Creek or non-salt-dome type of Gulf Coast oil field. The beds are relatively flat over the field, but dip sharply to the southwest in the southwest quadrant. Small production was developed from the Pliocene, but failed after several years, so that today there is no production at Welsh. The oil was of low gravity, 11° to 19° Baumé, but had especially high fire and flash points and a viscosity that made it especially desirable for car-journal oil. The field has some possibilities for discovery of deeper productive sands.

INTRODUCTION

LOCATION

The Welsh field is in Jefferson Davis Parish, southwestern Louisiana, about 3 miles west of the town of Welsh on the Southern Pacific Railroad, in sections 21, 22, 27, and 28, T. 9 S., R. 5 W. The developed portion is confined to the southeast quarter of Section 27 and the southwest quarter of Section 22.

PREVIOUS WORK

Comparatively little has been published on the Welsh field, and great difficulty has been experienced in obtaining well logs or reliable information on the history, development, and even the location of the wells in the field. This is explained by the fact that the operations were carried on, in the main, by individuals and small companies. Of the published literature, the writings of Harris are the most complete.[3] The only other data of real value have been obtained through the courtesy and co-operation of some of the oil companies in Houston, especially of The Texas Company, and the Rio

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[1] Published by permission of Mr. E. T. Dumble, consulting geologist, Southern Pacific Company.

[2] Geologist, Rio Bravo Oil Company.

[3] G. D. Harris, "Oil and Gas in Louisiana," *U. S. Geol. Surv. Bull., 429*, 1910; also *U. S. Geol. Surv. Bulls. 212*, p. 136, 1903, and *282*, pp. 102–5, 1906; and *Report La. Geol. Survey*, 1907, p. 35.

Bravo Oil Company, which made available several well logs, production data, and reports made by William Kennedy.

HISTORY

The discovery of Spindletop, near Beaumont, Texas, in January, 1901, brought about a search for similar structures throughout the Gulf Coast, and every topographical high was suspected of being a possible salt dome. During the following year this prospecting brought about the discovery of Anse La Butte, Jennings, Welsh, and Humble domes, and subsequently there were a number of others.

The surface indications suggestive of a dome at Welsh were a slight topographic elevation and a gas seep in a shallow water well on the Woods farm, located on the elevation. In the latter part of 1901, the Welsh Home Development and Oil Company drilled the first well on Lot 3, Block 6, Woods subdivision, southeast quarter of Section 27. This well was drilled to 1,050 feet. The hole was ruined, but the showings encountered warranted further development. The following year the same company had a blowout of sand from their well No. 2 at 1,000 feet. From that time the field was considered more seriously, but drilling activity has never been undertaken on a large scale.

The development has been intermittent all through the life of the field. From 1901 to 1910, according to reports made by William Kennedy to the Rio Bravo Oil Company, some 40 wells were drilled in the field within a radius of 2 miles. Since 1910, it is estimated that some 51 more wells have been drilled, making approximately 91 wells for the entire field to date.

Among the first producers was well No. 1 of the Southern Pacific (now Rio Bravo Oil Company), which was brought in January 2, 1903, at a depth of approximately 1,010 feet. This well continued producing until January, 1911. During that period it yielded a total of 72,000 barrels of oil.

The greatest production according to figures taken from *Mineral Resources of the United States*, was obtained in 1910. Since that year the production has gradually declined to almost nothing and virtually ceased in 1917. The wells have been pumped occasionally for local consumption. A few dry holes have been drilled since 1917, mainly deep tests. Two wells, 3,100 and 3,315 feet, were put down south of the railroad in the southeast quarter of Section 27. The deeper, Avery and Martin, well blew considerable gas from about 1,600 feet. In 1921 the Gulf Production Company drilled two deep wells, one north and the other northeast of the field. In 1923, Lucas *et al.* drilled a 3,200-foot hole on the southwest edge of the field. These tests were all dry. Hooks *et al.* are now drilling on the southwest edge of the proven area and are at present testing a sand at 1,758 feet. This sand is deeper than previous production and is reported to have given a promising showing.

TOPOGRAPHY

The country about Welsh is a featureless plain except for the slight elevation which called attention to possibilities of oil. At the field the elevation is 24 feet above sea-level, and there is locally as much as 10 feet relief. Figure 1 shows that there is an appreciable slope to the south and west. The crest of the hill is about 1 mile north of the field, where the rocks take a gentle dip to the north. Branching to the east from this hill is a decided ridge which crosses the railroad and then broadens out to form a low upland covering a relatively large area. On the east side of the ridge there are at least two distinct terraces, which have probably been caused by the slough that now has its channel about 2 miles east of the field.

STRATIGRAPHY

The Welsh field is in the wide belt known as the Gulf Coastal Plain, and the surface is composed of Beaumont clays. The well records show the thickness of these surface clays in the field to vary from 60 to over 200 feet, and they appear to lie unconformably upon the series of beds assigned to the Lafayette.

A general section typical of the field obtained from various logs shows about 100 feet of clay above the sands and gravels of the Lafayette formation, which, with partings of shale or gumbo, is taken to be about 800 feet in thickness. Downward from this depth there is probably a gradation into lower beds of the Pliocene.

Several oil sands, most of them shallow, are found in this field. As a rule, the wells obtained production from the first sand, as it has appeared to contain less salt water than the deeper ones. In the center of the field this horizon is 960 to 1,010 feet below the surface. Although a few higher and lower sands gave showings, the horizon mentioned is the main one.

The zone containing oil sands lies below the gravels and belongs either in the upper Pliocene or in transition beds. On account of the manner in which the wells were drilled at that early period, and the inadequate records kept, only a general conception of the actual character of the formations can be gained.

Some of the wells in the field have a thin "cap rock" immediately overlying the first oil sand. This rock is not the true cap rock found so often in the salt domes, but is merely a local induration of the sand caused by cementation. It varies from 1 to 6 feet in thickness and is sometimes merely a shell, and does not occur at a definite horizon.

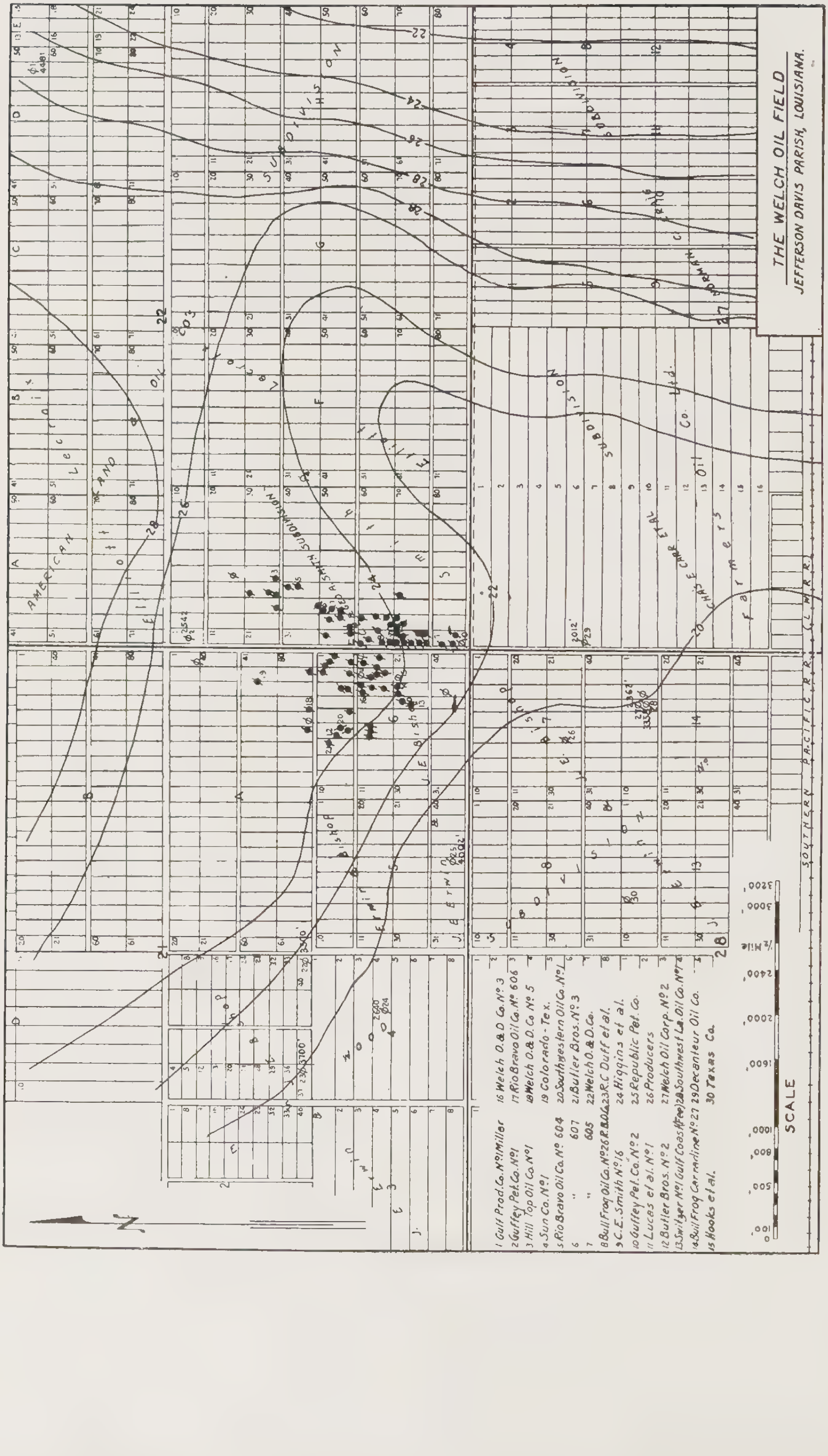

FIG. 1.—Topographic map of the Welsh oil field. Datum mean sea-level

There is doubtless considerable lensing of the sands and a gradation of sands into shales. It was established, however, that a more or less uniform zone to be relied upon for oil-bearing sands is present. Immediately overlying the sand when the thin cap is absent, or directly above the cap when present, is a bed of gumbo varying from 60 to 80 feet in thickness. This gumbo bed appears to be more uniform than the sand itself, and was used by the drillers as a marker.

Although the sand seems to be irregularly distributed throughout the field, with a thickness of 10 to 15 feet, it is thickest as a rule in the central portion, where it averages 20 feet.

The quality of the sands, like the thickness, varies in different wells, but the texture is fairly regular. Mr. Kennedy found the sand to be a white, translucent quartz of fairly even grain, angular, but with the sharp corners worn off. About 90 per cent remains on a 60-mesh screen, and half of the remainder will not pass the 80-mesh. While a little of the sand is very fine, it will not pass through the 120-mesh. From a test of the voids in the sand, it was estimated by Mr. Kennedy to have an oil capacity of 25 per cent. Some of the deeper sands that gave showings of oil were found to be extremely fine-grained and angular.

PALEONTOLOGY

A number of beds containing shells are mentioned in the logs, which should have thrown more light on the stratigraphy had the fossil beds been cored or specimens collected, but the only paleontological evidence remaining consists of a few bivalve shells from the Guffey, Rio Bravo well No. 605 and the Gulf Coast well. Of these, only one or two were sufficiently intact to be identified, and of the lot it may be said that the species are too long ranging to be of any assistance in determining the age of the formations. The list is as follows:

Rio Bravo Oil Co. well No. 605, 1,585–1,589 feet
    Rangia cuneata Gray
    Mulinea lateralis Say
    Rangia (?) *quadricentennialis* Harris

1,642–1,648 feet
    Rangia fragments

1,817 feet
    Rangia fragments
Guffey well, 1,800 feet
    Rangia sp. ?
??, 1,390 feet
    Rangia cuneata

Five cores of sands from various depths were recently secured from the well being drilled by C. G. Hooks *et al.* These cores were examined by E. Richards Applin, paleontologist for the Southern Pacific Company, who reports as shown in Table I.

TABLE I

Depth	Formation
1,355 feet..........	Core of dark gray, very fine-grained sand. Sand grains even in size and angular. A few, possibly 10 per cent, of the sand grains dark green and gray in color. No foraminifera or indications of other fossils. Good oil show.
1,400–1,500 feet....	Core of extremely fine, even-grained, light-gray sand, with a few worn fragments of some fossil shell. A very few small nodules of pyrite. Slight oil show.
1,500–1,600 feet....	Core of extremely fine-grained gray sand which contains at least 25 per cent of very fine fragments of finely splintered volcanic glass. Slight oil show.
1,616 feet..........	Core of sand as described at 1,400 feet but slightly coarser. Slight oil show.
1,758 feet..........	Core of material like above. Nothing to indicate its age. Slight show of oil.

The absence of Foraminifera, and especially the reworked Foraminifera so characteristic of the Miocene, strengthens the belief that the Pliocene still prevails at this depth.

STRUCTURE

There have been a few unsatisfactory deep tests made at Welsh, some on the structure, but the majority either on the flanks or entirely away from it. The wells are tabulated as shown in Table II.

None of the deeper wells reached salt, nor did they encounter structure peculiar to the typical domes where the salt core approaches the upper horizons. The log of Welsh No. 3 shows about 200 feet of rock or limestone, as indicated in the accompanying section, but no other well in the area records more than thin breaks of rock. Welsh must be classed, therefore, with such fields as Goose Creek, Orange, and Edgerly, until more thorough and deeper prospecting justifies a change in its status.

After plotting the logs for the two cross-sections of the field as shown in Figures 3 and 4, it was found that the only datum plane that could be used was the first oil sand, as no other formation was uniform enough to be correlated. Even this horizon has proved to be rather unsatisfactory, although immediately overlain by a fairly constant bed of gumbo which could be used in conjunction and as a check to give the interpretation of the subsurface structure presented.

TABLE II

Company and Well	Location	Subsurface Contour	Depth (Feet)
Producers Oil Co.	Lot 26, Block 7, Sec. 28, SW. of field	....	2,860
Republic Prod. Co.	Lot 36, Block 5, Sec. 21, SW. of field	Contour 1,250	4,002
Producers Oil Co.	S. of railroad track	....	3,000
Guffey Pet. Co. No. 1	Lot 1, Sec. 22, N. of field	Contour 1,000	2,542
Guffey Pet. Co. No. 2	Lot 71, Sec. 22, S. of field	Contour 1,025	2,446
Gulf Prod. Co. No. 1 Wright	Sec. 9, 2½ mi. N. of field	Contour 1,875?	3,511
Gulf Prod. Co. No. 1 Miller	Sec. 22, 1 mi. NE. of field	Contour 1,640?	4,481
Rio Bravo Oil Co. No. 605	Lot 43, proven area	Contour 975	2,640
C. E. Smith	Lot 6?, Block 6, Sec. 21	Contour 1,000	2,800
Lucas *et al*	Lot 19, SE. edge of proven area	Contour 975	3,200?
Hooks *et al*	Lot 22, SE. edge of proven field	Contour 1,000	Drilling
Welsh Oil & D. Co	Lot 40, Block 1, NW. of field	....	3,500
R. C. Duff *et al*	Lot 37, Block 1, NW. of field	....	3,700
Higgins *et al*	Lot 4, Block 4 W. of field	....	2,640
Avery & Martin, Todd No. 1	SE. quarter, Sec. 27	....	3,100
Welsh Oil & D. Co. & Getty	SE. quarter, Sec. 27	....	3,315

From the evidence available, the more abrupt dips appear to be to the southeast and southwest. Additional data may change this conclusion. The rate of dip appears to be somewhat as follows:

Center to north at the rate of 143 feet per mile
Center to east at the rate of 264 feet per mile
Center to south at the rate of 1,000 feet per mile
Center to west at the rate of 417 feet per mile

From data obtained by the well logs both in the field and on its edges, as shown by the subsurface contours and also by the varying thickness of the Beaumont clays, it is apparent that the upward movement has been of slight degree and intensity. The wells quite distant from the field are reported to have encountered surface beds

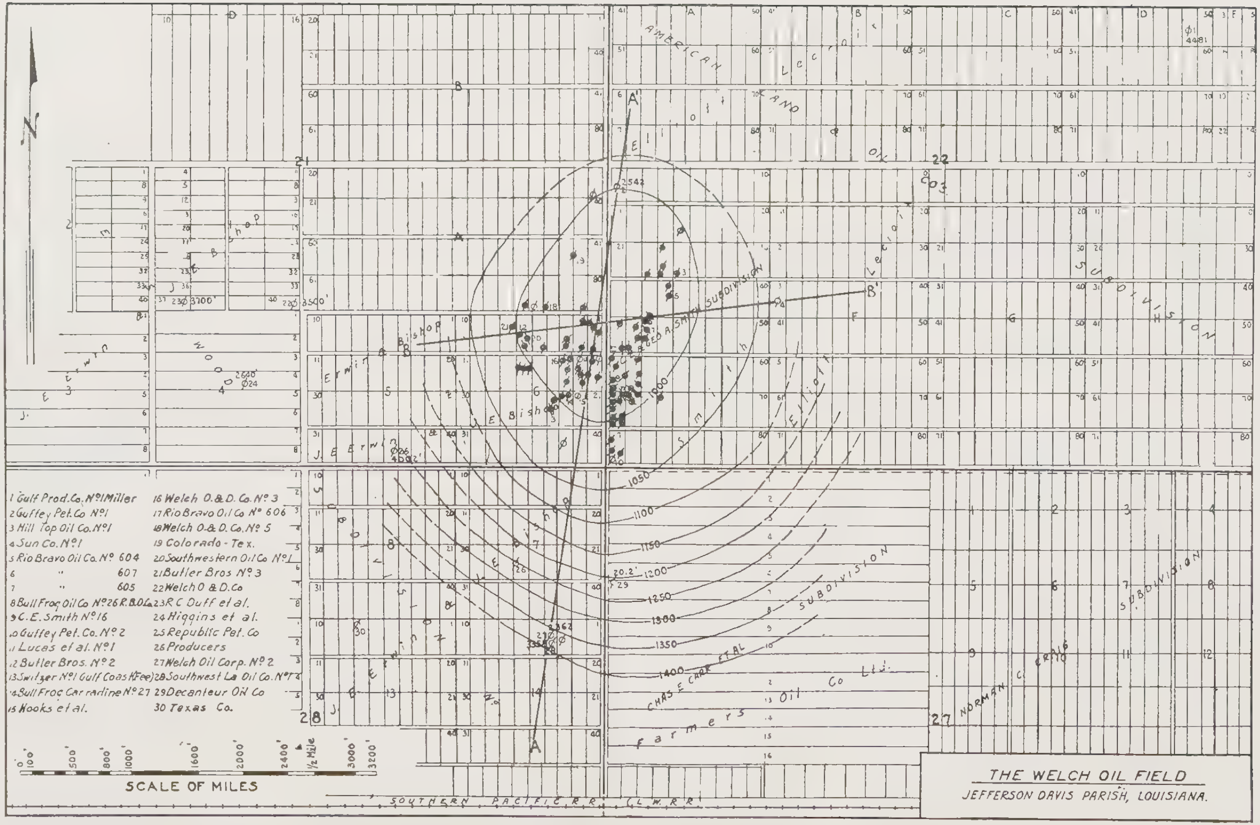

FIG. 2.—Structure contour map of the Welsh oil field. Contours on the producing horizon

of clays 200 feet and more in thickness, while within the producing area these clays are much thinner. Mr. Kennedy states that there is an

> overlying deposit of yellowish clay varying in thickness from 63 feet in the Rio Bravo Oil Company well to 105 feet in the Welsh Company No. 3 and 104 feet in the Rio Bravo No. 1. At the western or southwestern end of this ridge the clays thicken to 200 feet and more and the same condition appears to exist toward the northeast.

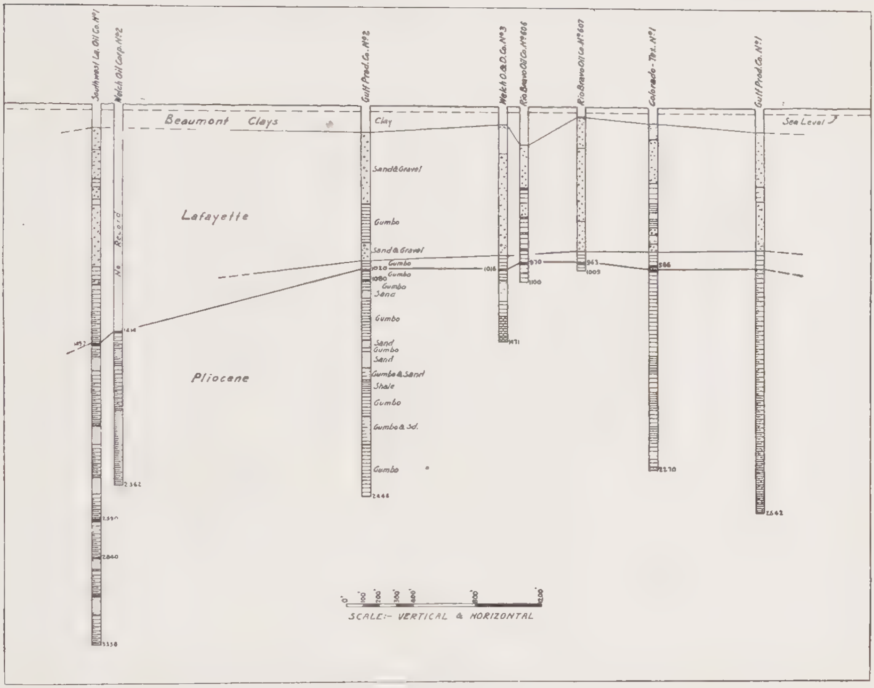

FIG. 3.—North-south structure section through the Welsh oil field, along line *A–A′* of Figure 2.

It thus appears that there has been movement subsequent to the deposition of the Beaumont clays. If there had been movement prior to this, the Lafayette formation should be noticeably thinned toward the top of the dome, but if this is the case, it cannot be detected from the well records. The thinning of the Beaumont clays is not of great amount, and the fact that the elevation still appearing at the surface has not been entirely eroded to the level of the surrounding plains is indicative that the movement has been of recent date, or that there has been subsequent movement, possibly still in progress.

The sands that furnished the major production were at the 1,000-foot horizon, were of relatively flat contour, and lay just below gravel beds of Upper Pliocene age. The deeper drilling, both of early and late years, has furnished no positive evidence of either lithologic or paleontologic nature to indicate that the Lower Pliocene has been penetrated and the possibilities of the Miocene explored.

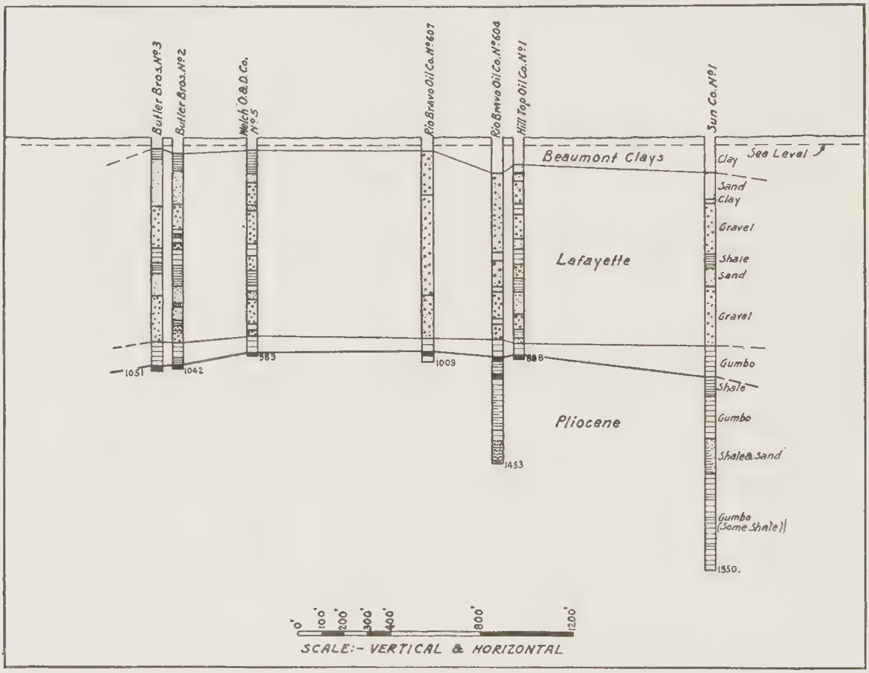

FIG. 4.—West-east structure section through the Welsh oil field, along line *B-B′* of Figure 2.

The relative flatness of the known oil horizon and the surface evidence furnished by the thinning of the Beaumont clays indicate that the slight doming of the upper strata may be only the reflex of more pronounced movements at greater depths. It is possible, therefore, that the lower formations may be found in a much more characteristic state of dome structure, and the deep sands, under these circumstances, may be reservoirs.

OIL AND GAS

Gas is found in the same sand as the oil, and at times under considerable pressure. The first serious blowout occurred in the second well drilled. Since then, several wells have blown gas with quantities of sand. The pressure was quickly exhausted, however, and there were no wells in the field classifiable as gas wells.

Only the upper portion of the sand contains oil, the lower part being filled with salt water. Most of the wells flowed for a few days when brought in, some as much as 200 barrels per day, but this initial production quickly settled down to about 15 barrels on the pump. Two wells are reported to have produced for five years, and well No. 1 on the Rio Bravo for eight years. As a rule, however, the wells did not have a long life and usually had to be abandoned within a year, as may be seen by production curves for the individual wells (Fig. 6).

Mr. Kennedy states that the oil from the Welsh field is characterized by its heavy gravity, dark color, and the faculty of retaining water in an emulsified form longer than the oils from other Coastal fields. From 14 to 21 per cent water remains in the oil until separated mechanically, the separation being fairly readily performed. At times a little fine-grained sand is found in the fluid.

The oil is all of low gravity, but it varies in different parts of the field, the comparatively lighter oil being found in the central portion. Oil from the McFadden well (near the margin) had a gravity of 11.5° Baumé, the Central City well near by, 12° Baumé, while wells of the Rio Bravo, near the center of the field, had a gravity of 17.5° to 19.9° Baumé. When the water is extracted, oil of 17.5° Baumé has a gravity of 19.5° to 23.5° Baumé. This oil has a turpene base.

Oil when freed from water and having a gravity of 19.5° Baumé showed a flash point of 225° F. and burning-point of 275° F. The viscosity as compared with oil from Spindletop at a temperature of 70° F. is demonstrated in a comparative test of these two oils as shown in Table III.

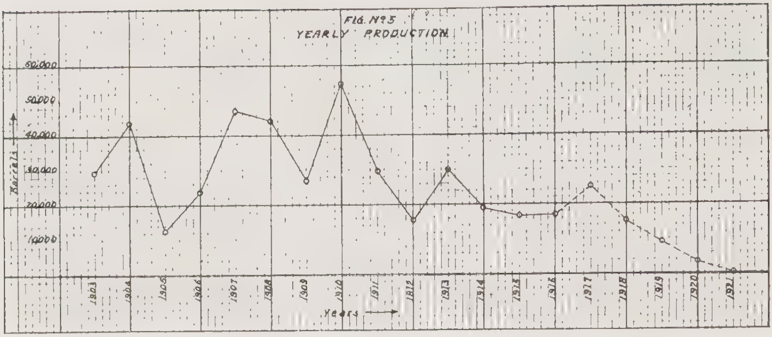

FIG. 5.—Curve of production by years for the Welsh oil field

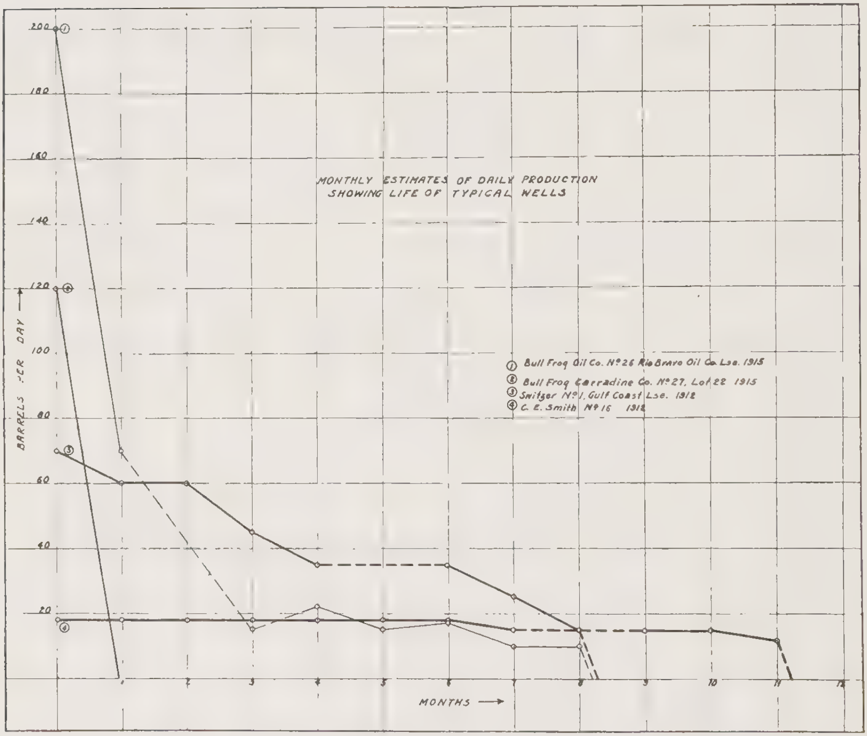

FIG. 6.—Curves of production by months for the Rio Bravo Oil Co., Bull Frog Oil Co. No. 26, the Bull Frog Carradine Co. No. 27, the Gulf Coast Oil Co. Switzer No. 1, and C. E. Smith No. 16.

During the years that Welsh was productive, a large percentage of the production was used by the Southern Pacific Railroad for journal oil. Owing to the high flash point, high fire point, and the high viscosity, it was very desirable for that purpose.

DRILLING METHODS

Rotary drilling-rigs similar to those employed in the early days in all Coastal fields were used at Welsh, and they were used in the same carefree manner that characterized drilling operations at that period.

PRODUCTION DATA

Figures for yearly and monthly production and for completions are obtainable from the annual reports of the *Mineral Resources of the United States*. After 1917, Welsh produced so little oil that its production has not been listed separately; so from that year, only estimated figures can be given. What has been pumped from the one or two wells since 1919 has been readily consumed for fuel by the local rice farmers. Up to 1917, the oil bought or produced from the Welsh field was piped by the Rio Bravo Oil Company to a siding near the field and run through a cleaning-plant before being used for car-journal oil. Curves have been plotted for yearly production and for the yield of characteristic wells (Figs. 5 and 6).

TABLE III

	Spindletop Oil	Welsh Oil	Galena Engine Oil
Gravity	22° B.	19.5° B.	25.2° B.
Flash point	180° F.	255° F.	
Fire point	200° F.	255° F.	
Viscosity at 70° F.	1	8.17	4.65

FUTURE OUTLOOK

From the fact that the production of this field in the upper horizons has been practically exhausted, and from the fact that the few deep tests made in the past have offered little or no encouragement, this field has lain dormant, and the general impression prevails that it is a closed chapter in oil history.

An analysis of the evidence and production so far obtained and an analysis of the operations in the past, viewed particularly from the standpoint of modern methods of testing cores of sands, leaves the results of the deep tests made in the past open to doubt as regards determinations of the oil-producing possibilities of the sands encountered.

The hypothesis is certainly admissible that the Lower Pliocene or Upper Miocene sands, when explored by modern methods, as at Orange, will probably approach more typical and favorable conditions for accumulation of oil and gas; and it is believed that the occurrence, quantity, and quality of the oil and gas so far recovered (apparently from Upper Pliocene sands) is indicative of larger and deeper deposits. See Table IV.

TABLE IV

ANALYSIS OF PETROLEUM FROM WELSH, LOUISIANA

Color	Olive Green
Odor	Pleasant
Specific gravity	19.2° B. at 60° F.
Viscosity	36.8°
Naphtha	1.05 per cent
Illuminating oil	30.07 per cent
Lubricating oils	65.38 per cent
Coke, gas, and loss	3.50 per cent
	100.00

F. C. Thiele, Beaumont, Tex., analyst. This oil is entirely free from sulphur.

TABLE V

List of Wells in the Welsh Field, Jefferson Davis Parish, Louisiana

Company	Well	Total Depth (Feet)	Oil Sand (Feet)	Initial Production	Date Completed	Remarks
......	Hilltop No. 1	960	960	Small	......	7 ft. of oil sand
......	Hilltop No. 2	960	960	12 bbls.	......	Junked
......	Hilltop No. 3	960	960	8 bbls.	......	
......	Hilltop No. 4	960	960	Small	......	
Southern Pacific Co	S. P. No. 1	1,006	1,006	......	......	
Southern Pacific Co	S. P. No. 2	970	970	......	......	Abandoned producer
Southern Pacific Co	S. P. No. 3.	970	970	......	......	Dry hole
Metropolitan Co	Metrop. No. 1	996	996	23 bbls.	......	Junked
Welsh O. & D. Co	No. 1	1,050	1,050	......	......	Abandoned producer
Welsh O. & D. Co	No. 2	1,050	1,050	......	......	Abandoned producer
Welsh O. & D. Co	No. 3	1,100	1,100	None	......	Blew out at 1,100 ft.
Welsh O. & D. Co	No. 4	1,020	1,020	50 bbls.	......	Pumped
Southwestern O. Co	No. 1	1,020	1,020	Gas	......	Gassed 3½ hours
Boss-McFadden	No. 1	1,030	1,030	......	......	
Texas Co	No. 1	1,200	1,200	None	......	Dry hole
Decatur O. Co	No. 1	2,012	1,140	None	......	Dry hole, oil at 1,400 ft.
Colo.-Tex	No. 1	2,340	1,000	......	......	Abandoned producer
Brown-Lively	No. 1	1,100	1,100	None	......	Dry hole, no oil
Taber	No. 1	1,025	1,025	......	......	
Welsh O. & D. Co	No. 5	2,000	1,800	None	......	Dry hole, 200 ft. oil sand
......	Butler No. 1	1,350	1,350	......	......	Abandoned producer
......	Butler No. 2	1,350	1,350	40 bbls.	......	Abandoned producer
......	Butler No. 3	1,350	1,350	......	......	Abandoned producer
Liberty S. & O. Co	Liberty No. 1	1,360	1,350	......	1918	Abandoned producer
Liberty S. & O. Co	Liberty No. 3	1,340	1,340	......	1919	Show of oil
Crescent O. Co	Crescent No. 2	1,350	1,350	......	1919	Show of oil
Liberty S. & O. Co	Liberty No. 2	1,345	1,345	......	1919	Show of oil
Crescent Oil Co	No. 1	1,340	1,340	......	1918	Show of oil
Crescent Oil Co	No. 3	1,350	1,350	......	1919	Show of oil
Crescent Oil Co	No. 4	1,360	1,360	......	1919	Show of oil
Scoggins, Jeter & Hackworth	No. 1	1,050	1,035	Small	1920	Pumping intermittently
Bull Frog O. Co	No. 1	940	940	......	......	
Bull Frog O. Co	No. 2	950	950	......	......	
Metropolitan	No. 3	910	940	......	......	
Southern Pacific Co	No. 4	950	950	......	......	
Metropolitan Co	No. 2	940	940	......	......	
Simms Oil Co	No. 1	2,000	......	......	......	
Republic Prod. Co	No. 1	......	......	......	......	
R. C. Duff *et al*	No. 1	......	......	......	......	
Welsh Oil Corp	No. 1	......	......	......	......	
Welsh Oil Corp	No. 2	2,397	......	None	1917	No show of oil
Guffey	No. 1	......	......	......	......	
Guffey	No. 2	......	......	......	......	
Scoggins, Jeter & Hackworth	......	......	......	......	......	
Liberty S. & O. Co	No. 4	......	......	......	......	
Flying Dutchman O. Co	No. 1	1,340	1,330	None	1917	No show of oil
......	Spindletop No. 1	1,700	......	None	......	Show of gas at 1,000 ft.
......	Wildcat No. 1	......	......	None	......	No trace of oil
Smith, Switzer, *et al*	......	1,600	......	None	1910	Reported that the driller said the formation was very much broken up and he did not go deeper on this account. Exact location not determined
Sun Co	No. 1	......	......	......	......	
Higgins Oil & Fuel Co	No. 1	......	......	......	......	
Central City	No. 1	......	......	......	......	
Central City	No. 2	......	......	......	......	
Central City	No. 3	......	......	......	......	
Peter Lamp	No. 1	......	......	......	......	
S. Keoughan	No. 1	......	......	......	......	
Ala.-Southwestern	No. 1	......	......	......	......	
Ala.-Southwestern	No. 2	......	......	......	......	
Ala.-Southwestern	No. 3	......	......	......	......	
Gulf Prod. Co	Miller No. 1	......	......	......	......	
Gulf Prod. Co	Wright No. 1	......	......	......	......	

Total, 61 wells.

THE SULPHUR SALT DOME, LOUISIANA

P. K. KELLEY
Houston, Texas

ABSTRACT

The sulphur salt dome in Louisiana is a typical Gulf Coast salt dome, but is exceptional in its small area, about 75 acres, in the very great thickness of the cap, about 1,000 feet, and in the richness of its deposit of native sulphur. The cap is composed of anhydrite and a mantle-like mass of "lime" rock covering the top and flanks of the anhydrite. The sulphur is found as a secondary mineral in the transition zone between the "lime" rock and the anhydrite and has probably been precipitated from hydrogen sulphide or metallic sulphides in solution. After a long history of vain expensive attempts to mine the sulphur, the Frasch process was perfected, by which the sulphur is melted in place and pumped in liquid form to the surface. The total production to date has been about 9,000,000 tons of sulphur with a gross value of $150,000,000. Small amounts of heavy oil were encountered in the early sulphur wells, but not in commercial quantity. The flanks have not been well tested for oil.

INTRODUCTION

LOCATION

The salt dome in Calcasieu Parish, Louisiana, operated for sulphur by the Union Sulphur Company, is in the north half of Sec. 29, T. 9 S., R. 10 W. It is ½ mile north of the main line of the Southern Pacific Railroad, ¼ mile from the Old Spanish Trail highway, and 6 miles from the Kansas City Southern Railway. The nearest town is Lake Charles, 13 miles to the east. The village of Sulphur is 2½ miles distant. The sulphur mine is served by a short railroad line, the Brimstone Railroad and Canal Company, which connects the property with the two lines.

HISTORY

The locality first attracted attention because of a petroleum seep. Just before the Civil War, Dr. Kirkman, a local physician, drilled a well in the southeast corner of Section 19. This location happened to be some 1,500 feet away from the dome. In spite of primitive methods, he pushed down to below 450 feet, where gravel stuck his pipe and put an end to the enterprise.

After the war, the Louisiana Petroleum and Coal Oil Company drilled a well 1,230 feet deep into the cap rock, a log of this test given by Hilgard and Harris[1] being as follows:

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[1] G. D. Harris, *U. S. Geol. Surv. Bull. 429* (1910), p. 100.

TABLE I

Log of Well of Louisiana Petroleum and Coal Oil Company

Feet	Thickness in Feet	Depth in Feet
Yellow and blue clay	160	160
Gray and yellow sand	173	333
Lime rock at	....	333
Blue sandy limestone	50	383
White crumbling limestone	65	448
Pure sulphur	203	651
Gypsum containing sulphur	39	690
Gypsum containing large percentage of sulphur	440	1,130
Gypsum containing sulphur	100	1,230

After discovery of the sulphur, various efforts to exploit it were made. A company financed in France undertook to sink a shaft to the mineral. Elaborate equipment, including large-diameter iron caisson in sections, was shipped from France, unloaded on the west bank of Calcasieu River, whence it was hauled, dragged, and rolled to Sulphur Mine. Before all the rings had left the river bank, the shaft encountered quicksand and filled up with water and hydrogen sulphide gas. After several men working in the bottom of the excavation had been killed, the French syndicate quit, with a loss of nearly a million dollars. Nothing remains of their enterprise but one of the huge iron rings, which is still reposing on the bank of Calcasieu River with a pine tree 2 feet in diameter growing through the middle of it.

Some years later the American Sulphur Company undertook the same work with more modern methods. After many vicissitudes and the expenditure of a large sum of money, they found themselves fighting a losing battle with quicksand and went for advice to Mr. Herman Frasch, a chemical engineer of wide experience, especially in the fields pertaining to the refined products of petroleum and salt. In 1892 Mr. Frasch conceived the idea of melting the sulphur in the ground and pumping it out as a liquid. The property had lain idle after the various ineffectual attempts to develop it and was not regarded as much of an asset by its owners, at that time the Louisiana Sulphur Mining Company of New Orleans. Negotiations by which the Union Sulphur Company acquired title were completed in 1893, and Mr. Frasch started work on his problem. Drilling and experimental equipment uncovered many unsuspected problems, both in the physics of the method and in the geology of the deposit and necessitated endless changes in the mechanical devices applied to the exploitation of the sulphur. After ten years of discouragement, the property was put on a commercially producing basis by means of what is now known as the Frasch process. No history of this operation, however short, can be complete unless it includes a tribute to the courage and perserverance of Herman Frasch, the father of the American sulphur industry.

Since 1903, the property has been in successful commercial operation.

PHYSIOGRAPHY

An attempted restoration of the principal topographic features of the district to conditions before changes effected by the mining operations of the Union Sulphur Company is given in Figure 1.

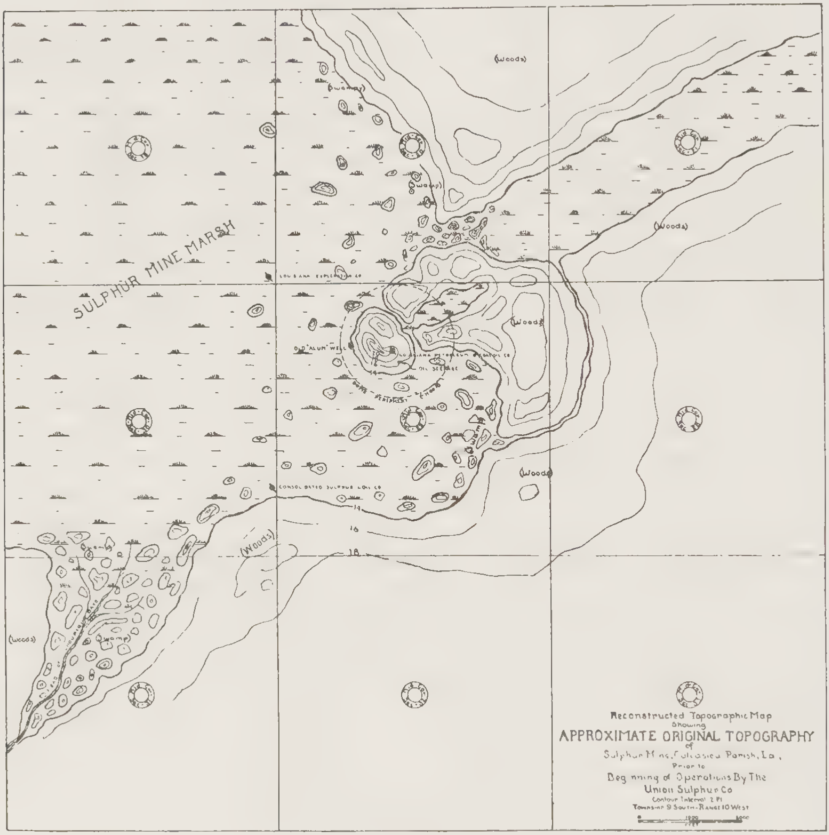
SULPHUR MINE MARSH
(Woods)
(Swamp)
Old "Alum" Well
Oil Seepage
Consolidated Sulphur Co
14
16
18
Reconstructed Topographic Map
Showing
APPROXIMATE ORIGINAL TOPOGRAPHY
of
Sulphur Mine, Calcasieu Parish, La.,
Prior to
Beginning of Operations By The
Union Sulphur Co
Contour Interval 2 Ft
Township 9 South - Range 10 West

FIG. 1

Before the surficial irregularities of the region were rendered less apparent by artificial drainage, a magnolia-studded ridge, later called Sulphur Mine, projected southward from the southern edge of the piney woods into Sulphur Mine marsh. This marsh, now drained and tilled, was formerly a shallow intermittent lake, some 8,000 acres in area, grown up with lush bamboo. The ridge itself was not high. The Marsh level is 14–15 feet above sea-level, and the highest portion of the ridge was not over 7 or 8 feet above the marsh.

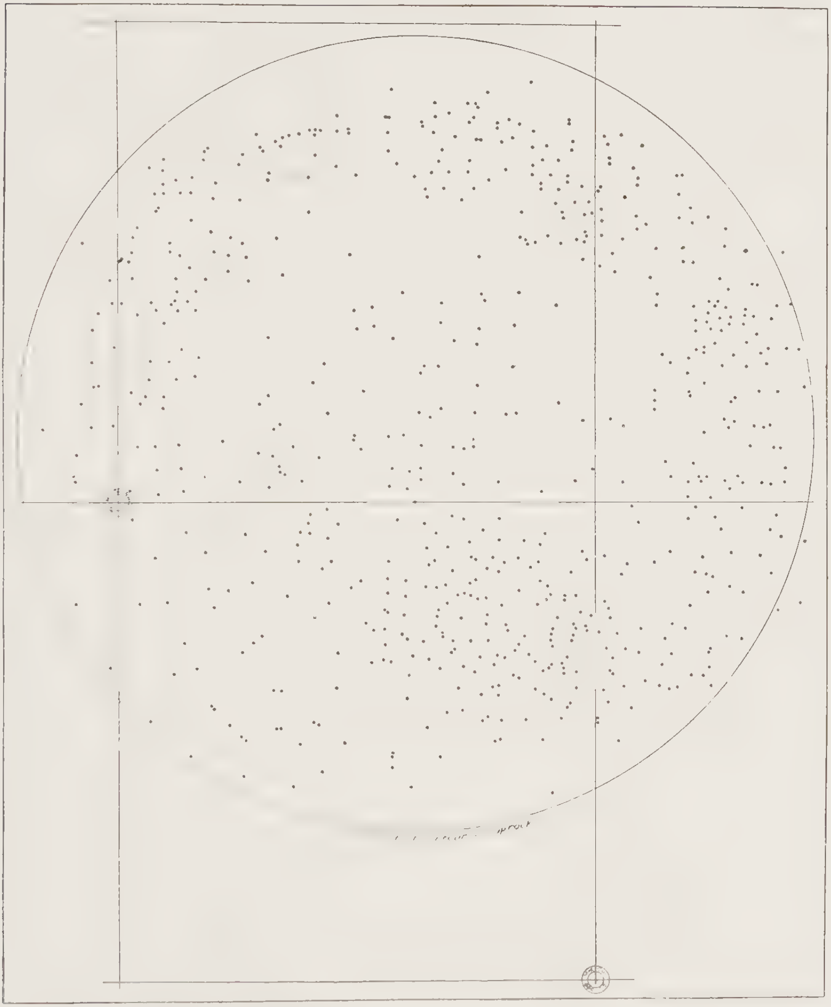

FIG. 2.—Map of wells drilled on the sulphur salt dome, Sec. 29, T. 9 S., R. 10 W., Calcasieu Parish, Louisiana.

Two peculiarities distinguished this ridge. The first was a petroleum seep or spring, the position of which is indicated in

Figure 1. This seep was perennial and was not affected by rainfall. The volume of fluid was very small. The second was an "alum well," or seep, at the edge of the marsh, on the extreme western side of the ridge. There is no record of any analysis of this water. No cil accompanied this flow, but there was some gas. Its astringent quality was no doubt due to a small admixture of sulphuric, or, more probably, sulphurous acid. The water oozed to the surface over a soft, mucky, grass-covered place some 12 or 15 feet in diameter.

GEOLOGY

Sulphur Mine has the smallest cap-rock area of any of the coastal domes. At 1,100 feet below sea-level its area is approximately 75 acres. It is almost perfectly circular in plan.

Figure 2 shows the wells drilled to date, 661 in number. The large number of wells drilled into the cap rock makes possible a contour map of the dome top, graduated to a smaller scale than usual. Contours on the top of the cap rock are shown in Figure 3; they are accurate in a general sense, but may vary from the original form of the cap rock to the extent that the figures supplied by more recently drilled wells are affected by possible subsidence, due to the removal of the underlying sulphur.

A typical well log, from the surface to the top of the cap, shows an ordinary section of blue, yellow, and red clays, alternating with sandy clays and sands, to about 250 feet (Beaumont clays), where a fine water-saturated sand is encountered, and then Lafayette gravel to the cap rock. The elevation of the top of these gravel beds is affected very little, if any, by the upthrust of the dome immediately below them; on the flanks of the dome, however, they are from 100 to 300 feet thicker than on the top. This situation suggests the possibility that the top of the dome was exposed at the surface, during a part of Lafayette time. The writer has examined hundreds of cores from this cap rock, but no fossils have been found. There has been insufficient drilling around the sides of the dome to supply paleontological evidence, should any exist, as to the period or periods in which uplift occurred, except that the inception of the movement antedated Pleistocene time.

The four cross-sections, Figures 4, 5, 6, and 7 show the steep quaquaversal dips, and characteristic structure typical of the true salt dome. The sections are generalized. The transition from cap

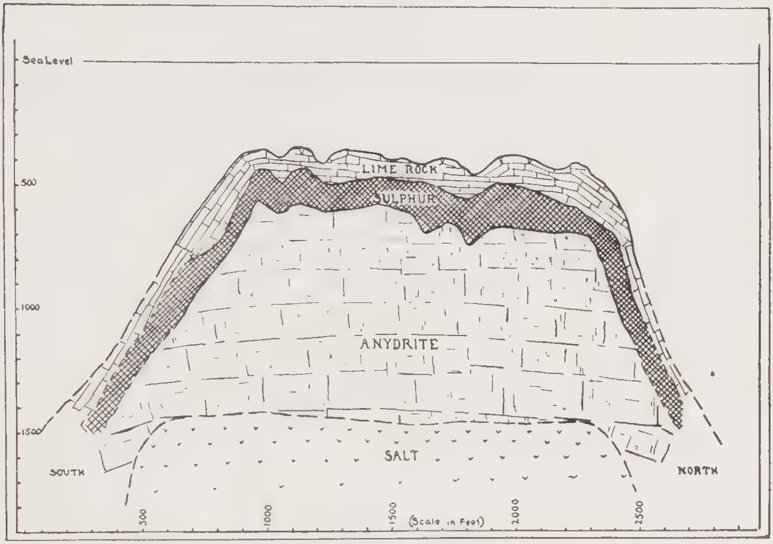

Fig. 4.—Sulphur salt dome, Louisiana, north to south section

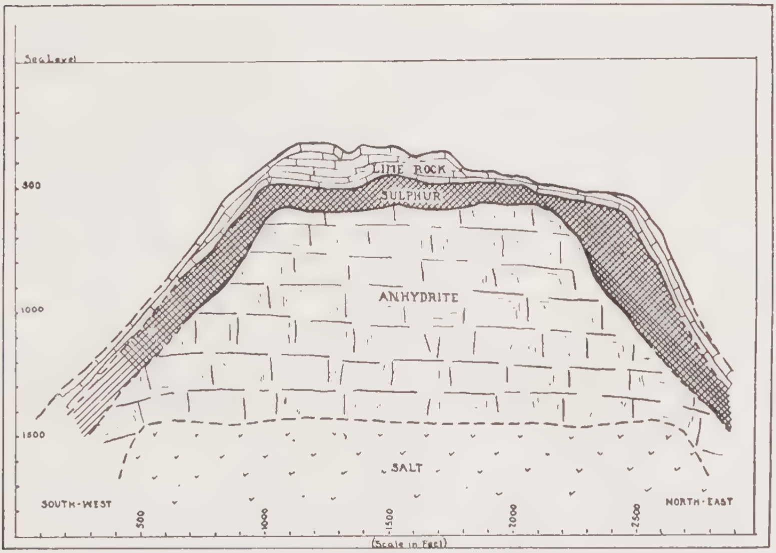

Fig. 5.—Sulphur salt dome, Louisiana, northeast to southwest section

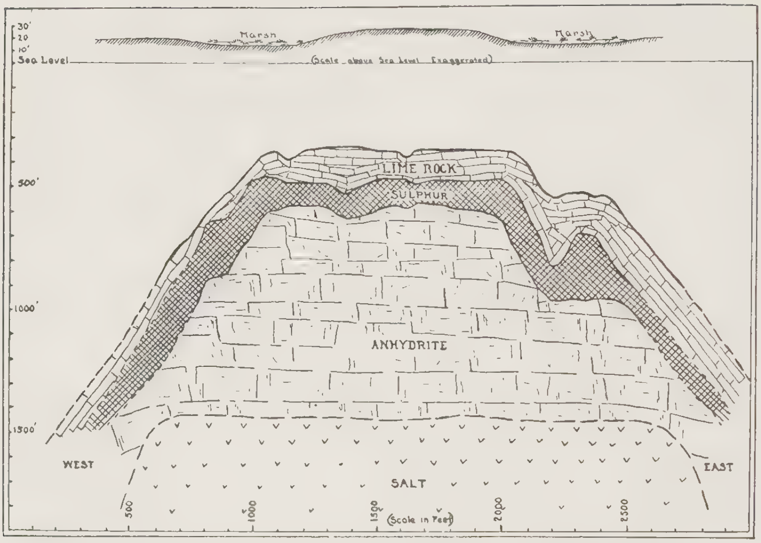

FIG. 6.—Sulphur salt dome, Louisiana, east to west section

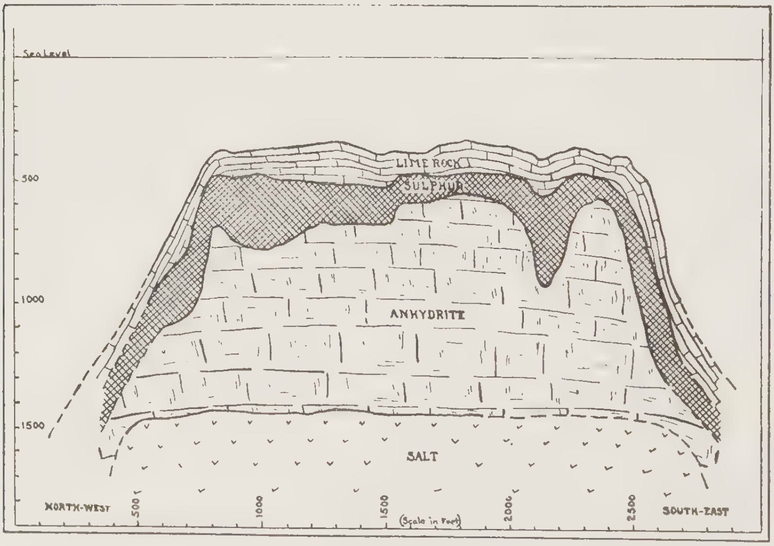

FIG. 7.—Sulphur salt dome, Louisiana, northwest to southeast section

rock to sulphur-bearing rock, and from the latter to gypsum and anhydrite, although abrupt in places, most commonly is gradual.

The truncated top of the salt core is nearly level. Wells drilled 1,500 feet apart, with a difference in the elevation of the cap rock of several hundred feet, find the salt about the same depth, i.e., 1,460–65 feet below sea-level. No deep wells have been drilled on the sides close to the salt core, but the information obtained from shallow drilling indicates steep dips.

Unusual thickness of the cap-rock series marks this dome. The thickness of the cap rock superimposed upon the top of the salt core averages about 1,100 feet, of which some 900 feet is non-sulphur-bearing, practically pure anhydrite. The sulphur-bearing rock lies like a mantle, covering the top and sides of this anhydrite.

Different sections, perpendicular to the surface of the cap rock, whether on the flank or the top of the dome, display approximately the same thickness of sulphur-bearing formation. The gangue in the sulphur-bearing zone includes limestone, dolomitic limestone, anhydrite, and gypsum. There is a gradual vertical transition from limestone at the top of the zone through a mixture of limestone, calcite, gypsum, and anhydrite, to pure anhydrite at the base. The sulphur content is extremely variable; locally, the deposit ispure sulphur, but at the base of the zone it may contain as little as 1 per cent sulphur.

Over the sulphur-bearing rock is what the sulphur operator calls "cap rock," the nomenclature differing from that of the oil operator, who calls the entire rock series above the salt cap rock. The character of the cap rock at Sulphur Mine varies considerably, and consists in different places of the following: practically pure limestone impregnated with oil; limestone with calcite-filled cavities and veins, sandy limestone (one sample analyzed 48 per cent silica; the sand grains were cemented with calcium carbonate), and dolomitic limestone with magnesium content less than that of a true dolomite. All these may occur in the same vertical column of cap rock, with no uniformity or continuity, even as between two closely adjacent wells.

It is interesting to note that this upper cap rock contains little or no gypsum. The depositon of sulphur crystals is apparently largely confined to the zone which marks the transition from the non-sulphur-bearing limestone cap to the non-sulphur-bearing anhydrite immediately overlying the salt. Unless the transition zone is present, no sulphur is encountered; the volume of the sulphur deposit varies directly with the thickness of the zone; and the richness of the sulphur deposit varies directly with predominance of carbonates over sulphates in the gangue. Other factors are important, of course; porosity, polysulphide waters under hydrostatic head; the presence of hydrocarbons, possibly some catalytic agent, all of these fit into one or more of the various theories for the origin of sulphur; but to the writer's knowledge, there does not exist in any dome a commercial deposit of sulphur where there is not also a considerable thickness of this transition zone. It therefore behooves the sulphur prospector to search out the thickly capped domes: where the entire cap-rock series is thin, the transition from the carbonate series to the sulphate series is abrupt, if indeed any carbonate is present at all, and consequently but little sulphur will be found.

OIL AND GAS

Wells drilled on the outer rim of the cap rock have passed through ledgelike projections, jutting out from the main body of rock. Between these projections lie sands and clays. Some oil occurs in these sands, but so far no effort to exploit the flank for oil has been made. In the early stages of the sulphur mining, two or three wells drilled into the top of the cap produced some heavy black oil. One well tapped the original gas pressure accompanying the oil, and flowed for a day or two at the rate of several hundred barrels per day. As soon as the gas pressure was relieved, the well started making sulphide water, and it was soon apparent that this well had about exhausted the cap-rock oil. This "gusher" gave rise to many erroneous ideas concerning the existence of a proved field, and kept the Sulphur Company busy denying wild rumors for several years thereafter.

SULPHUR

Various articles in the technical press of the country have described the Frasch process. Briefly, it provides for melting the sulphur *in situ* by means of superheated water. The liquid sulphur is then brought to the surface by an air lift. The typical equipment, shown in Figure 8, can be modified to accommodate the special peculiarities of the well section, e.g., as to leanness, richness, or continuity of mineralization and presence of cavities. It permits egress of superheated water at any one of three different horizons in the sulphur-bearing zone, or all of them simultaneously, at the desire of the operator.

To conduct a mining operation at any major deposit requires an installation of from 15,000 to 30,000 boiler horse-power, and accessory equipment, consisting of heaters, pumps, pipe-lines, drilling rigs, receiving vats, railroad, oil and water storage, a water-supply of 10,000,000 gallons daily, etc., so that the initial expenditure is heavy. After the investment is made, sulphur recovery on a commercial basis is by no means certain; in fact, sulphur-mining is a much more hazardous business than producing oil. Once successfully on the way, however, it pays handsome dividends. From Sulphur Mine there have been produced about 9,000,000 tons of sulphur with a gross value of about $150,000,000.

Principally contributing to this large total is the higher price obtained for the product during the period the Union Sulphur Company had a natural monopoly on the American market. The present average per ton price is considerably lower.

Logs of two typical wells, (1) on top of the dome, and (2) on the side, follow:

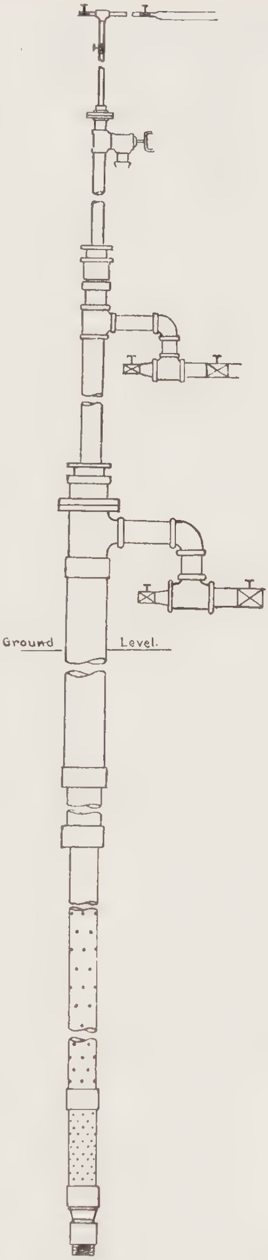

Fig. 8.—General assembly of a sulphur well

1. RECORD OF TYPICAL WELL ON TOP OF DOME

	Depth in Feet
Sands, clays, and gravels	1–443
Lime rock	443–695
Limestone and sulphur	695–696
Porous, lost returns	696–710
Limestone, gypsum,* and sulphur, (core)	748–749
Limestone and fair sulphur, (core)	770
Limestone, gypsum, and sulphur, (core)	789–790
Limestone, gypsum, and sulphur, (core)	809–811
Limestone, gypsum, and little sulphur, (core)	829–830
Gypsum and little sulphur, (core)	849–851
Limestone, gypsum, and fair sulphur, (core)	869–870
Limestone, gypsum, and good sulphur, (core)	889–890
Limestone, gypsum, and sulphur, (core)	907–909
Gypsum and no sulphur, (core)	927–929
Total depth	939

2. RECORD OF TYPICAL WELL ON THE SIDE OF THE DOME

	Depth in Feet
Sands, clays, and gravel	540
Limestone	540–660
Limestone, becoming porous	660
Sulphur crystals first appear	660
Limestone and sulphur	660–666
Cavities	666–667
Limestone, some sulphur	667–676
Cavity	676–680
Limestone, some sulphur	680–800
Limestone and little sulphur, core	800–802
Limestone and little sulphur, core	825–827
Limestone and little sulphur, core	861–862
Limestone and little sulphur, core	886–888
Limestone and no sulphur, core	911–912
Limestone and no sulphur, core	936–937
Limestone and no sulphur, core	961–962
Limestone and no sulphur, core	986–988
Limestone, no sulphur, core	1,010–1,011
Limestone, no sulphur, core	1,030–1,031
Limestone, little sulphur, core	1,055–1,056
Limestone and little sulphur, core	1,080–1,081
Limestone and very little sulphur, core	1,105–1,106
Limestone and fair sulphur, core	1,130–1,131
Limestone and good sulphur, core	1,155–1,156
Cuttings, little limestone, extra good sulphur	1,156–1,181
All sulphur	1,166–1,168
Cuttings, limestone, gypsum, and good sulphur	1,168–1,192
Limestone, gypsum, and little sulphur, core	1,192–1,198
Limestone, gypsum, and good sulphur, core	1,216–1,217
Cavity	1,217–1,218
Limestone and gypsum and good sulphur, core	1,241–1,242
Lost returns at	1,254
Limestone, gypsum, and sulphur, core	1,265–1,266

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* No effort was made in this log to differentiate gypsum from anhydrite.

	Depth in Feet
Limestone, gypsum, and good sulphur, core	1,292–1,293
Limestone, gypsum, and good sulphur, core	1,336–1,337
Cavity	1,349–1,350
Gypsum, limestone, and good sulphur, core	1,374–1,375
Limestone, gypsum, and good sulphur, core	1,400–1,402
Lost core at	1,425
Drilling changed	1,455
Gypsum, and no sulphur, core	1,459–1,461
Gypsum, and no sulphur, core	1,474
Salt	1,480
Depth of hole	1,610

ORIGIN OF THE SULPHUR

A great deal has been written both at home and abroad on the origin of the sulphur. A short bibliography is appended for the benefit of those who care to go into the more important chemical, geological, and physical hypotheses thus far brought forward.

Some of the factors upon the presence of which the existence of sulphur is conditioned are: (1) a relatively thick cap-rock series, with thick mass of carbonate overlying the gypsum-anhydrite; (2) a relatively thick transition series between the two, partaking of the character of both; (3) great porosity in the transition series; and (4) polysulphide waters circulating in the porous rock.

Regardless of how the cap-rock series in general is formed, sulphur is unquestionably a replacement material. The weight of the evidence indicates also that the actual precipitation of sulphur crystals occurs only from the sulphides, either as pure gases, as gases in solution, or as metallic sulphides in solution, principally of the calcium-magnesium group.

Analyses of the mine drainage water for two typical wells follow; the drainage water consists of a mixture of the "wild" waters naturally present in the rock and the fresh water pumped in during the mining operations.

1. ANALYSIS OF MINE WATER FROM SULPHUR DOME

Temperature	150–195° F.
Salt	50–1,000 grains per gal.
Sulphur in sulphides	50– 200 grains per gal.
Total solids	150–1,500 grains per gal.

2. ANALYSIS OF A TYPICAL WELL LOW IN SALT (WELL No. 328)

Total solids	190.74
Iron and alumina F_2eO_3, Al_2O_3 (Fe 203, Al 203)	0.60
Silica (SiO_2)	3.60
Salt (NaCl)	41.40
Calcium sulphide ($CaSO_4$)	114.48
Calcium Carbonate ($CaCO_3$)	22.51
Sulphur in sulphides (S)	5.10
Ignition loss not sulphur	2.53
	190.22

Waters high in salt are low in sulphides, and vice versa; waters with a high salt content have also a high sulphate content; and as these two constituents increase, other salts diminish until almost all the total solids consist of calcium sulphate and sodium chloride. Magnesium commonly is present but only in small quantity.

OIL POSSIBILITIES

Two deep wells have been drilled on the west side of the dome, one in Section 19 by the Louisiana Exploration Co., and one in Section 30 by the Consolidated Sulphur and Oil Company. The locations of the wells, neither of which was productive, are shown in Figure 1. The logs of the wells are as follows:

LOG OF HUNTER No. 1—LOUISIANA EXPLORATION COMPANY*

CALCASIEU PARISH, LOUISIANA

SE. COR. SE. ¼ SE. ¼ OF SEC. 19, T. 9 S., R. 10 W., CALCASIEU PARISH, LOUISIANA

	Depth in Feet		Depth in Feet
Red clay	40	Cavey sand	490
Hard broken sand	47	Sand and gumbo	550
Clay and hard sand	77	Gumbo and gravel	620
Gumbo	107	Hard gumbo	628
Hard sand	108	Gravel	647
Quick sand, clay breaks	225	Packed sand	663
Gumbo	235	Hard sand and gravel	690
Stiff clay	250	Blue shale	729
Still clay	308	Fine gravel	750
Sand	365	Packed sand	756
Sand and gravel	413	Hard, broken sand	778

* Shells showed continually in cuttings from 2,987 to 3,390 feet, inclusive. Tested salt water. After pulling liner ran steel line 2,824 feet to bottom of hole.

	Depth in Feet
Loose gravel	785
Blue gumbo	809
Soft gray sand rock	812
Sand rock	815
Hard and soft sand	835
Tough gumbo	850
Shale and gumbo	876
Tough gumbo	880
Gumbo and shale	909
Hard and soft shale	930
Tough gumbo	938
Hard and soft shale	960
Tough gumbo	985
Sandy shale, shell, and lignite	1,033
Sandy shale	1,075
Hard shale	1,140
Sandy shale	1,166
Hard gumbo	1,197
Shale	1,230
Gumbo	1,250
Shale	1,280
Gravel	1,320
Gumbo	1,350
Sand	1,400
Gumbo	1,420
Gypsum	1,440
Gumbo	1,500
Hard sand and blue shale	1,521
Shale and bowlders	1,535
Gumbo	1,605
Shale and bowlders	1,665
Gypsum	1,685
Packed sand	1,691
Gypsum	1,693
Coarse sand and gravel	1,706
Coarse sand and gumbo breaks	1,785
Sand, gravel, and gumbo	1,800
Gumbo	1,820
Sand	1,850
Shale	1,900
Soft white rock	1,902
Gumbo	1,903
Sand and shell	1,987
Coarse sand and gravel	2,005
White sand and bowlders	2,010
Tough gumbo	2,020
Packed sand	2,027
Hard, broken rock and gravel in beds	2,035
Gravel and bowlders	2,055
Gumbo	2,065
Gravel	2,080
Gumbo	2,094
Tough gumbo and gravel	2,136
Tough gumbo and gravel	2,184
Gumbo	2,222
Gravel	2,287
Gumbo	2,307
Sand and gravel	2,408
Gumbo and bowlders	2,428
Gumbo	2,490
Gumbo	2,513
Gumbo	2,565
Sandy shale	2,640
Hard red shale	2,700
Shale	2,717
Loose shale	2,738
Hard shale	2,754
Loose shale	2,775
Hard gumbo	2,790
Chalk rock	2,794
Sand	2,840
Sand	2,882
Packed sand	2,840
Red shale	2,860
Chalk rock	2,864
Red shale	2,880
Gray sandy shale	2,911
Chalk rock	2,916
Hard shale	2,955
Shale	2,987
Gumbo	3,007
Gumbo	3,037
Gumbo	3,057
Gumbo and bowlders	3,082
Pyrites of iron	3,100
Pink shale	3,124
Pink shale	3,140
Pink shale	3,160
Bowlders and shale	3,180
Pink gumbo	3,198
Rock and pyrites	3,220

	Depth in Feet
Rock and pyrites	3,240
Gumbo and shale	3,270
Gumbo and shale	3,285
Rock and gumbo	3,300
Gray shale	3,310
Gumbo and pyrites	3,321
Gumbo and shale	3,331
Gumbo and rock	3,341
Gumbo and bowlders	3,350
Bowlders and gray shale	3,360
Gray shale and shell	3,380
Gumbo	3,390
Gumbo, red and blue, very tough, pyrites and some lime in cuttings	3,433
Hard drilling, lime, sand, shale, lignite and pyrites in cuttings	3,468
Pink shale, lime streaks, and a little sand	3,532
Lime rock	3,545
Gumbo	3,552
Lime rock	3,557

LOG OF WELL OF CONSOLIDATED SULPHUR AND OIL COMPANY*

Sec. 30, T. 9 S., R. 10 W., Calcasieu Parish, Louisiana

	Depth in Feet
Gumbo and sand	1–534
Blue gumbo	554
Blue shale	575
Shale	959
Sand	765
Gumbo	811
Mud and shell	877
Shale and mud streaks	1,120
Gumbo and hard shale	1,180
Very tough gumbo	1,188
Gumbo and rotten lime	1,195
Sand and shale	1,250
Shale	1,270
Pink gumbo	1,290
Green shale	1,310
Shale and gumbo	1,352
Fine white sand	1,375
Blue gumbo	1,415
Shale	1,435
Blue gumbo	1,450
Shale	1,470
Gumbo	1,475
Shale and pyrites	1,524
Hard shale and pyrites	1,540
Gumbo and hard shale	1,600
Shale and sand	1,620
Hard shale, sand gas	1,640
Gumbo	1,652
Gypsum	1,660
Shale	1,679
Gumbo	1,710
Green shale	1,730
Gumbo	1,740
Shale	1,750
Gumbo	1,770
Shale and sand	1,790
Gumbo and bowlders	1,800
Rock	1,804
Shale, sand, and some gas	1,844
Gypsum and bowlders	1,882
Gumbo	1,920
Shale and sand	1,947
Gumbo	1,969
Shale and sand	1,990
Pink gumbo	2,012
Hard shale	2,034
Gumbo and pink shale	2,055
Shale and pyrites	2,078
Shale and bowlders	2,099
Gumbo	2,121
Shale and pyrites	2,130
Gumbo	2,150
Shale, pyrites, bowlders, gas	2,182
Gumbo and gypsum	2,237

* Set screen on December 18, 1915, bottom of screen 2,876 set in gumbo. Set 6-inch 2,847 in gumbo pay 2,853–59. Good pay, 2,859–66. Breaks of pay in shale, brown and red, into rock 2 feet and sand to 2,876. Set 1,193 feet of 8-inch pipe. Pay rock, 2,853–2,861.

	Depth in Feet
Soft sand	2,265
Gumbo	2,286
Gumbo, red streaks	2,320
Sand	2,341
Gumbo and gypsum	2,355
Shale and sand	2,381
Rock	2,383
Sand and shell	2,400
Blue gumbo	2,420
Green shale	2,435
Gumbo	2,450
Shale and sand	2,465
Gumbo	2,490
Green shale	2,505
Gumbo and red shale	2,512
Red sand	2,515
Red gumbo	2,534
Shale and sand	2,588
Red gumbo streaks	2,620
Gypsum rock	2,625
Gypsum and gumbo	2,650
Red gumbo and gypsum	2,681
Red and blue shale	2,715
Red and blue gumbo	2,720
Red and blue shale	2,800
Tough and hard gumbo	2,810
Rock	2,811
Sand	2,812
Gumbo	2,815
Pink shale	2,833
Pink shale	2,835
Red and blue gumbo	2,853
Oil show, rotten rock	2,859
Oil	2,853–66
Oil show, rotten rock	2,866
Gumbo	2,868
Gypsum, brown shale, and oil show	2,870
Hard places, oil show, brown shale	2,884
Rock and oil show	2,886
Hard sand and oil show	2,892
Gumbo	2,895
Rock	2,897
Gumbo and shale	2,932
Tough gumbo and soft places of red shale	2,942
Good gumbo	2,958
Shale	2,970
Shale mixed color	2,984
Hard dry shale	2,994
Gumbo	3,105
Hard shale	3,128
Gumbo and shale	3,140
Shale	2,955
Soft shale	3,190
Hard shale	3,198
Gumbo and gypsum streaks	3,209
Gas rock rotten gypsum	3,212
Mud and seams of sand and pyrites	3,290
Gas rock	3,294
Gumbo and pyrites	3,343
Tough gumbo and gypsum	3,351
Muck, shells, and muddy shale	3,360
Gumbo, shale, and pyrites	3,370
Gumbo and seams of shells and pyrites	3,379
Shale, shell, and gas showing	3,392
Gumbo and gypsum	3,408
Blue shale and shells	3,430
Shale and pink gumbo	3,474
Rock gypsum, gas, and some oil	3,477
Shell, pyrites, mixed color	3,481
Blue and pink gumbo	3,490
Gypsum rock	3,492
Gumbo and gypsum	3,502
Gumbo	3,531
Gumbo, shale, and sand seams	3,537
Gumbo	3,574
Gumbo and shale break	3,584
Gumbo and hard shale seams	3,593
Hard shale	3,623
Gumbo	3,633
Gumbo and gypsum, hard places	3,639
Gypsum rock, soft places	3,642
Gypsum rock, upper 2 feet very hard	3,648
Hard shale and sand, some gas	3,679
Tough gumbo	3,697
Rock, gas showing	3,705
Shale	3,736
Gumbo and gypsum rock	3,780

	Depth in Feet
Shale streaks blue and brown sand	3,829
Very tough gumbo	2,835
Hard shale	3,884
Gypsum and gumbo	3,910
Gypsum rock, hard and smooth, all seams gas	3,931
Gypsum and gumbo, blue very hard	3,952
Gypsum rock, hard and seams show oil and gas	3,965
Hard sand oil and gas, stop in rock	3,984
Hard rock	3,995
Crystallized sand, hard places	4,016

	Depth in Feet
Hard red shale, pyrites sand streak	4,016
Gypsum and gumbo	4,030
Sand and gas (show fine)	4,042
Gypsum and gumbo, red blue tough	4,065
Hard sand shale, blue and brown oil show	4,075
Gypsum and hard sand	4,102
Seams of very tough gumbo	4,104
Crystallized sand and pyrites	4,108
Crystallized sand and pyrites	4,112
Gypsum	4,130
Rock, fine, showing oil very light	4,137

One unusual advantage presented by this dome is the fact that one owner has title to all fee completely surrounding it. There would be no difficulty in testing all sides of the dome, under a single lease.

Oil seems to be most plentiful in shallow sands along the north and east sides of the dome, and while no close-in deep drilling has been done, the information developed by shallow holes indicates a slightly more gradual dip on the northeast slope.

ACKNOWLEDGMENTS

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THE EDGERLY OIL FIELD, LOUISIANA

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ABSTRACT

The Edgerly oil field is located in the southwestern part of Louisiana in a topographically featureless part of the Gulf Coastal plain. Exploration for oil was based on gas seepages, and though a total production of more than 55,000 barrels of oil per acre has been obtained from the field, there is no indication of a salt dome other than the local steep dips away from the field. No salt, gypsum, or cap rock has been encountered in any well. There are four main producing sands, at average depths, respectively, of 2,700, 2,900, 3,000, and 3,100 feet.

SITUATION

The Edgerly oil field is located in Calcasieu Parish, Louisiana, in Sec. 28 and 29, T. 9 S. R. 11 W. (Fig. 1). The field is ½ mile north of the town of Edgerly, on the main line of the Southern Pacific Railroad approximately midway between Beaumont, Texas, and Lake Charles, Louisiana.

HISTORY

Gas escapes and so-called "paraffin dirt" were noted near Edgerly as early as 1906. On the Lillard property there were several gas seeps which boiled constantly when the area was under water, and which when dry could be detected by the strong odor of hydrogen sulphide gas. The seeps cover a circular area 10–15 feet in diameter, in crossing which one has the feeling of walking upon very stiff gelatine or rubber. There were also considerable showings of live gas in the marsh near the northeast corner of Section 28.

These indications were first brought to the attention of the Higgins Oil Company by Lee Hager in 1906. This company undertook exploration of the area, locating their initial test in the center of Section 28. Drilling was begun September 10, 1907, and the well was carried to 1,820 feet, where salt water was encountered. It was then decided to perforate the well at 1560 feet, and, on doing so, the well blew out making considerable dry gas and sand. Although several oil showings were reported while drilling, the well was abandoned after the blow-out. A second test was made about 300 feet north of No. 1. This well was drilled into salt water and abandoned at 2,025 feet. Well No. 3 was drilled 600 feet south of No. 1 and abandoned at 1,980 feet without finding anything of importance. In the early part of 1910, Hooks *et al.* drilled a well about 250 feet east of the Higgins Oil Company's No. 1, and at a depth of 1,200 feet, a showing of 16°

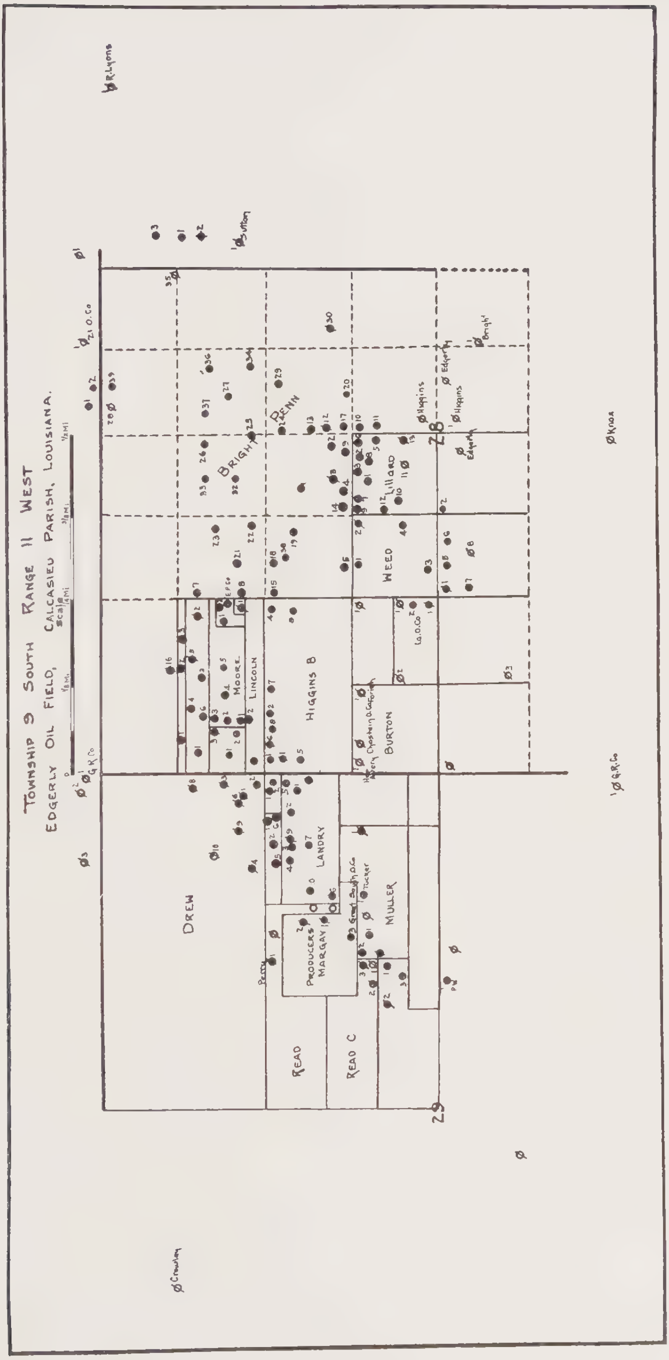

FIG. 1.—Map showing location of Edgerly oil field

Baumé oil was encountered. However, the well failed to produce oil and after being drilled to 2,477 feet was abandoned. Another well was located 200 feet east of No. 1 Hooks and was abandoned at 1,600 feet without any show of oil or gas. Later, two other wells were drilled, one by the Twenty-one Oil Company, being located in the southeast corner of the southeast quarter of the southwest quarter of Section 21, and the other by the Bright Oil Company (Jim Sutton *et al.*) on the Bright property. These wells were abandoned at 2,360 and 2,500 feet, respectively, without encountering anything of interest.

The first producing well was drilled in the southeast corner of the northeast quarter of the southeast quarter of Section 28, by the Bright Oil Co. At 1,300 feet the first test was made, resulting in a 2,000-barrel salt-water flow with five barrels of oil. The well was deepened to 1,500 feet, one joint of 2½-inch strainer set, and the well flowed 250 barrels of 17.5 Baumé oil. The discovery resulted in the acquisition of the Bright Oil Company's properties by the Gulf Refining Company of Lousiana on March 29, 1912.

GEOLOGY

There is no topographic relief at Edgerly; the surface slopes gently to the south in conformity with the general slope of the Texas-Louisiana Gulf Coast area. Although a number of deep tests have been drilled, none of them have encountered cap rock, gypsum, or dolomite; thus this field is to be placed in the same class with Goose Creek, Orange, and Welsh, at none of which has any direct evidence of a salt dome been revealed.

The production occupies an oval area approximately 5,000 feet east and west by 1,400 feet north and south. Edge wells reveal steep dips to the north, south, and west, and are characterized by the presence of mottled red and blue shales with thick beds of coarse sands, typical of edge wells in other fields of this type. The few fossils obtained from the Edgerly field have been determined as Pliocene, and it is doubtful if any of the production is obtained from older beds.

The principal producing horizons are the 2,700-, 2,900-, and 3,100-foot sands as illustrated in Figure 2. In addition to these horizons, an area of ten or fifteen acres in the southeastern portion of the field produces from a depth of 2,300 feet.

Correlation is made more certain by water analysis. The writer[1] has previously discussed the application of chemical analysis of waters to correlation. On the basis of the data presented in that discussion, the salt concentration of the 2,300-foot horizon may be

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[1] "Chemical Relation of Salt Dome Waters," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8 (1925), pp. 38–41.

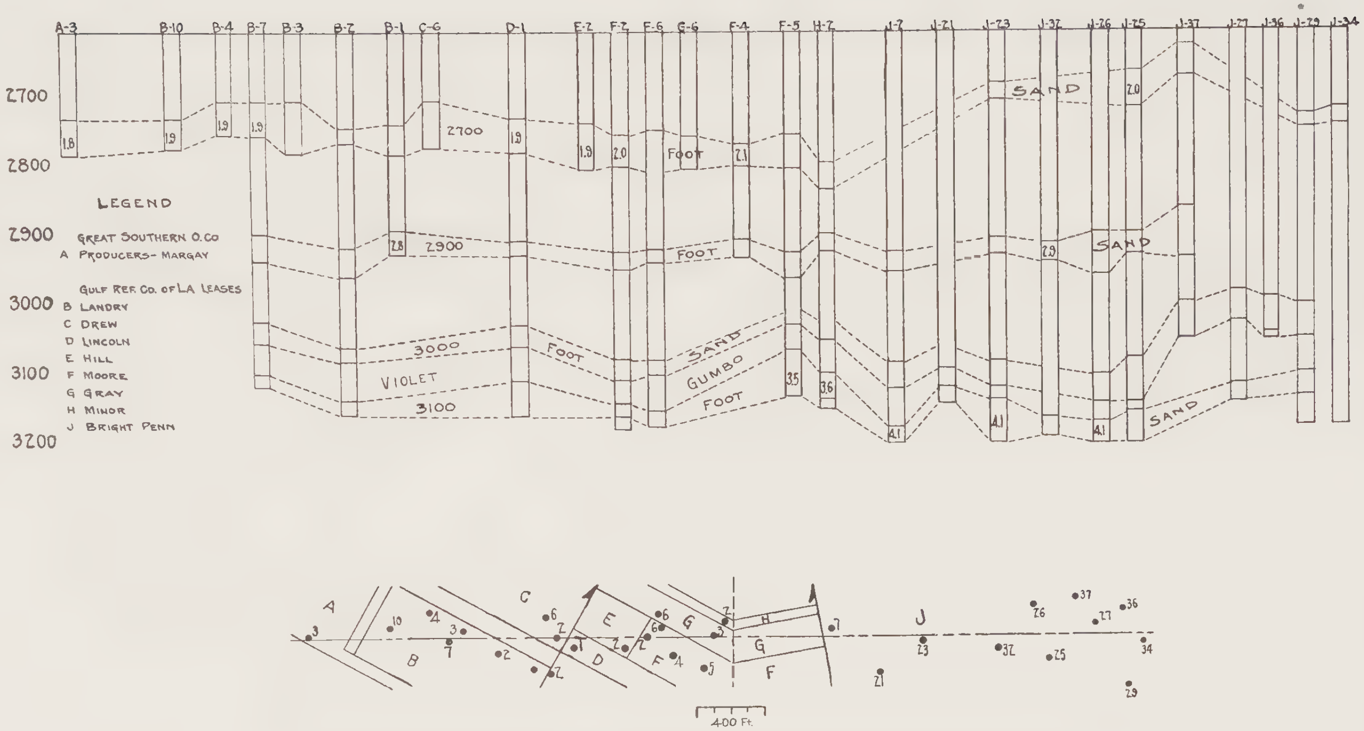

FIG. 2.—Section across field, Edgerly, Louisiana, showing principal producing horizons

interpreted as indicating a vertical uplift from 300 to 500 feet greater than in the field proper (Fig. 3). The 2,700-foot sand is very persistent in areal extent, and since it is composed almost entirely of fine breccia, is easily identified. This sand assumes a true dome structure with a closure of about 60 feet, the apex being near the southeast corner of the Drew lease of the Gulf Refining Company of Louisiana. The greatest production occurs along the crest of the fold, the major axis of which trends in a northeast-southwest direction. The 3,000- and 3,100-foot sands are interbedded with a violet-colored gumbo which serves as a key bed in the correlation of the strata. Good wells have been completed in these sands over most of the area of the field, showing that these sands are more persistent than any of the other producing horizons.

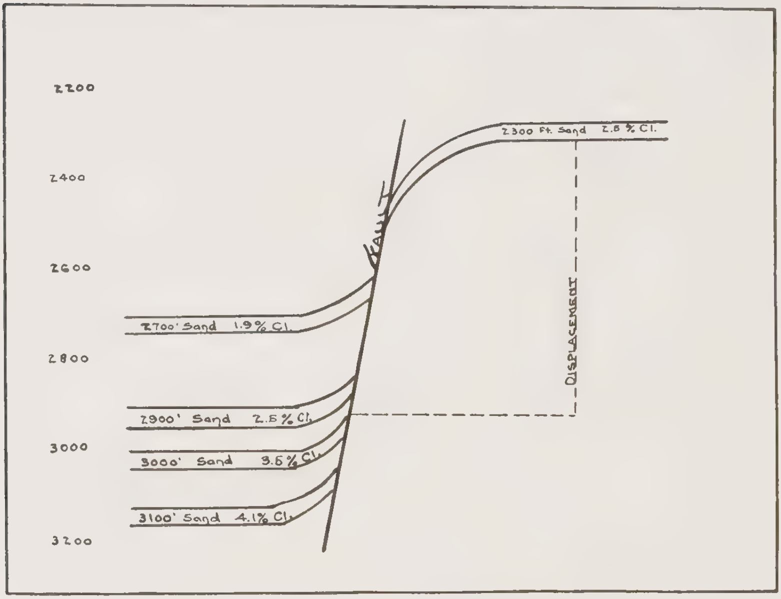

FIG. 3.—Diagram of faulted area

DEEP EXPLORATORY DRILLING

None of the deep tests that have been drilled at Edgerly has revealed any deeper producing horizon than the 3,100-foot sand.

In the center of the field the Gulf Refining Company of Louisiana drilled their Bright-Penn No. 38 to 5, 425 feet, without finding deeper production. On the northeast boundary line of the field, Bright-Penn No. 28 of the same company was carried to 3.280 feet. A mile farther east, the Richard Lyons No. 1 was abandoned at 3,918 feet. On the northwest side of the field, Drew No. 10 was drilled to 4,275 feet. To the southeast on the Maurice J. Muller lease, the Miller Oil Company drilled their No. 2 to 3,910 feet without results. To the south the Gulf Refining Company of Louisiana drilled No. 1 Higgins "C" to 3,737 feet, No. 2 Wilson to 3,668 feet, and No. 8 Higgins "A" to 3,720 feet. On the west, Bright-Penn No. 30 was drilled to 3,887 feet. With deep tests practically surrounding the field, there is little chance for an extension of the present productive area.

CHARACTER OF OIL

The oil produced from Edgerly is typical Gulf Coast crude, ranging in gravity from 19°-to 22.5° Baumé. None of the light gravity or freak oil encountered in other salt-dome fields has been developed. The refined product makes an excellent lubricating oil. The analysis of an Edgerly crude oil is given below:

ANALYSIS OF AN EDGERLY CRUDE OIL

Gravity: 18.9° Bé. Sulphur: 0.31
Color: almost black Boiling-point: 420° F.

Per Cent	Degrees F	Gravity
10	521	30.6
20	568	26.5
30	612	24.0
40	638	21.9
50	662	21.5
60	660	22.6
70	644	24.1
80	620	26.1
90	688	24.3

PRODUCTION

The production curve (Fig. 4), shows a gradual decline from a peak of 1,688,862 barrels in 1915. The decline has been very regular and practically free of periodic peaks which are so common to most of the salt-dome fields. The total production for the Edgerly field at the close of 1923 was 6,880,000 barrels, which gives a total of 55,000 barrels per acre, but with water encroaching and practically all of the area within the limits of production drilled, it is doubtful if it will ever exceed 70,000 barrels per acre. The daily average production of January, 1924, was distributed as follows:

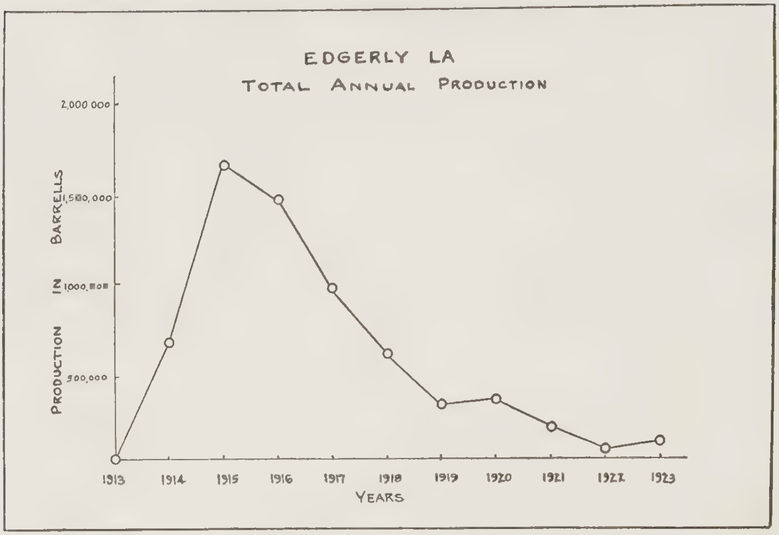

FIG. 4.—Production curve

TABLE I

Company	No. Wells	Production in Barrels
Gulf Refining Co. of La	12	267
Great S. O. Co	1	15
Muller *et al*	1	15
Emerson & Sutton	1	10
G. W. Gray	1	12
A. L. Gibson	5	93
Lake Charles P. Co	1	14
Total	22	426

The Gulf Refining Company's E. J. Fairchild No. 1, completed April 23, 1914, at a depth of 3,170 feet with an initial production of of 6,000 barrels, is the banner well of the field. This well produced until 1918, making a total of 226,158 barrels of oil. There have been more than a half-dozen wells which have produced over 100,000 barrels of oil each.

DRILLING METHODS

On account of the comparatively soft nature of the strata at Edgerly the rotary method of drilling is exclusively used. The cost of drilling and equipping wells ranges from $7,000 to $10,000 for 2,300-foot wells and $20,000 to $25,000 for wells completed in the 3,100-foot sand. The average well is drilled in from thirty to forty-five days.

PRODUCING PRACTICE

All wells are pumped with the standard rig using steam power. A considerable amount of water is producing with the oil, necessitating the treating of the emulsion, which is done almost entirely by steam plants located upon the various leases.

FUTURE POSSIBILITIES

In view of the comparatively small productive area at Edgerly and the apparent absence of deeper producing horizons, it is not probable that drilling activity will ever resume an upward trend. Stimulation of the market may promote further drilling and the re-working of old wells, but water is encroaching in all of the producing sands and the future will depend on the ability of the producers to extract the remaining oil by careful drilling and skimming methods.

THE SPINDLETOP SALT DOME AND OIL FIELD JEFFERSON COUNTY, TEXAS[1]

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ABSTRACT

The Spindletop oil field was the first and one of the most brilliant of the Gulf Coast oil fields. Spindletop is a characteristic Gulf Coast salt dome and is composed of a steep-sided, relatively flat-topped, circular salt core with a diameter of about 1 mile, and with a limestone, anhydrite, gypsum cap surmounting the salt. Most of the oil was produced from the porous cavernous limestone at the top of the cap. The early gushers have never been equaled in the United States for the size of their daily flush production. Few fields in the United States of like size, 265 acres, have had as big a production, thirty million barrels in the first three years, and a total of over fifty million barrels to date.

INTRODUCTION

Location.—Spindletop is in the northeast part of Jefferson County, in southeast Texas, about 3 miles south of Beaumont. The field is reached by means of the Sabine and East Texas Railroad, the interurban line running from Beaumont to Port Arthur, but best by automobile via either the upper or lower highways from Beaumont to Port Arthur.

History.—The Spindletop oil field is one of the oldest and most famous fields in the Gulf Coast region. The name was derived from a so-called island of timber, located on the northeast corner of the John A. Veatch survey, near the dome. The contour of the timber resembled an inverted spindletop when viewed from surrounding prairie.

The oil history of Spindletop dates back to about 1890 when one Patillo Higgins insisted confidently on the presence of oil under Spindletop. His convictions were based on two indications: the escape of gas from two points known as the copperas pond and the mud springs; and the distinct topographic elevation of the area above the prairie. Though nothing was known about salt domes or oil fields in the Gulf Coast at the time, Mr. Higgins laid out a section known as Gladys City and in 1892 formed a company known as the Gladys City Oil Company. Later, several water wells were dug to a depth of 15 to 20 feet, and sour waters containing various minerals were obtained. In addition to other indications, incrustations of sulphur were found in the soil.

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[1] Printed by permission of the Rycade Oil Corporation.

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The first oil tests were drilled in 1893. W. B. Sharp and J. S. Cullinan drilled a 418-foot well with a small rotary. Hearing that a gas sand had been passed up at 60 feet in the Sharp-Cullinan well, Mr. Higgins drilled nearby, and at about 60 feet completed a small gasser which supplied enough gas to fire his boiler. Other tests were drilled at about the same time by Looney and the Savage Brothers.

In 1900, Captain Anthony F. Lucas, a mining engineer, came to Beaumont. As the result of his experience with salt domes in southern Louisiana, he became convinced that sulphur, oil, and gas occurred beneath such domelike mounds as at Spindletop. Backed by Guffey and Galey, Lucas drilled his No. 1 well on the apex of the dome and though he lost it at a depth of 575 feet, two demijohns of 17° Baumé oil were obtained. The well that was later known as the "Lucas gusher," the fame of which spread around the world, was started in October, 1900, on the southwest slope a short distance from the apex.

On January 10, 1901, while drilling at a depth of 1,139 feet (352 m.), the well blew in unexpectedly with an enormous production that was conservatively estimated as 75,000 barrels (10,900 metric tons) per day. It is said to have shot a 6-inch stream of oil 200 feet into the air. Although oil had been showing in the ditch, no production had been expected and no preparations had been made to handle it. The well ran wild and flooded the surrounding prairie with oil. After flowing a few days, the well caught fire, and when it was finally brought under control, the casing was found to have collapsed. The well was never reconditioned.

The Lucas gusher was probably the first large or even moderate-sized well that was drilled with rotary tools. In some of the earlier tests, attempts had been made to drill with cable tools, but these had been unsuccessful on account of the loose, unconsolidated character of the sediments. Captain Lucas, therefore, turned to the rotary method which had been used in a rudimentary form at Corsicana, in a few water wells, and in one of the previous tests at Spindletop. He had, however, to do considerable pioneer work in redesigning it and in developing its technique.

Following the completion of the Lucas gusher excitement was high and land formerly worth $10 an acre jumped to thousands of dollars an acre. The Gladys City Oil Company secured the services of Captain Lucas to manage the drilling on its lease. Shortly they changed their name to the Gladys City Oil & Gas & Mfg. Company and began subleasing the 2,200 acres which they had leased for a period of twenty years. The land was assigned to companies and individuals without any cash bonus, allowing free oil and gas for fuel and retaining only one-tenth royalty. The company ceased drilling operations and became a royalty company.

Much land was obtained from the Veatch League, and the entire dome was leased and divided into various sections. The most prominent and important divisions are the Gladys City, in approximately the center, the McFaddin tract and Keith Ward to the south, Hogg-Swayne to the southeast, Yellow Pine and Lone Acre to the north, and Block No. 21 to the west. The most intensive drilling was on the Hogg-Swayne and Keith Ward tracts, where derrick legs overlapped one another, and from one to four holes were drilled under the same floor. By the summer of 1901, the boom was in full swing. Derricks were so closely spaced that derrickmen, fearing a blow-out, are said to have put out planks to neighboring derricks, in order to permit retreat from one derrick top to another out of the danger zone. The field reached the height of drilling operations and production during the year 1902 when the amount of oil gauged was 17,420,949 barrels (2,541,000 tons). Not included is an unknown very large amount of wasted oil. The wells were brought in so fast that it was utterly impossible to provide storage for all the oil, and, as a result, many thousands of barrels of oil covered the prairie and were lost.

By the end of 1902, the crest of the boom had passed and the drilling began to decline. During 1903, the production dropped to half that of the preceding year, but was still very large, even for Gulf Coast oil fields of the first class. By 1904, the limits of the field were pretty well shown to be confined to the area of the mound; the host of wells which were drilled around the edges of the field failed to bring in extensions to it, and successful new drilling was largely on proved acreage. The production dropped to 40 per cent of that of the preceding year. In 1905 it dropped again by 50 per cent, and for the next eight years it declined slowly but was still of moderate size. By 1915, the annual production had dropped below 400,000 barrels, and operations came to consist of working over old wells and drilling new wells to sands that had been undetected or ignored in the early days. During the past year, eight new wells were drilled, and the daily production averaged about 850 barrels (124 tons).

As the result of the discovery in recent years of production from deep lateral sands about various salt domes, exploration was renewed around the Spindletop dome. The Texas Company drilled a deep test into the salt on the northeast edge of the dome, and Wilson and others drilled nearby. The Spindletop Deep Well Company in the first part of 1917 drilled a test to 3,832 feet (1,150 m.) on Block No. 27 of the LaSalle Townsite Company. Many of these offside wells reported good shows, but none found oil in commercial quantity. Drilling in the latter half of 1918 on the northeast edge of the dome, the Gulf Production Company completed their McFaddin No. 1 as a 250-barrel (36-ton) producer at a depth of 2,947 feet (898 m.). The well in some way became junked and was never reconditioned. The Gulf Production Company's No. 2 McFaddin, 500 feet (150 m.) to the southeast of No. 1, was then drilled to 3,278 feet (999 m.); No. 3 McFaddin, a short distance off the southeast edge of the salt, to 3,780 feet (1,152 m.); No. 4 McFaddin was drilled 1,000 feet off the salt on the northwest into the top of the salt; and Gladys City No. 1 was drilled to 4,700 feet. About the same time, Marrs McLean drilled to 3,700 feet (1,128 m.) a short distance off the salt on the west. None of these wells found anything more than small shows of oil. In 1922, the Rycade Oil Corporation (formerly Amerada Petroleum Corporation) drilled its McFaddin No. 1 to a depth of 4,162 feet (1,296 m.), about 700 feet (200 m.) east of the Gulf Production Company's McFaddin No. 1. In a sand at 3,895 feet (1,187 m.) the well tested fifteen to twenty barrels (2½ tons) per day, on the swab. The Rycade Oil Corporation drilled its McFaddin No. 2 to a depth of 5,400 feet (1,647m.) just off the southeast edge of the salt and in 1924 drilled its Gladys City No. 1 to a depth of 3,962 feet (1,207m.) on the northwest flank of the dome.

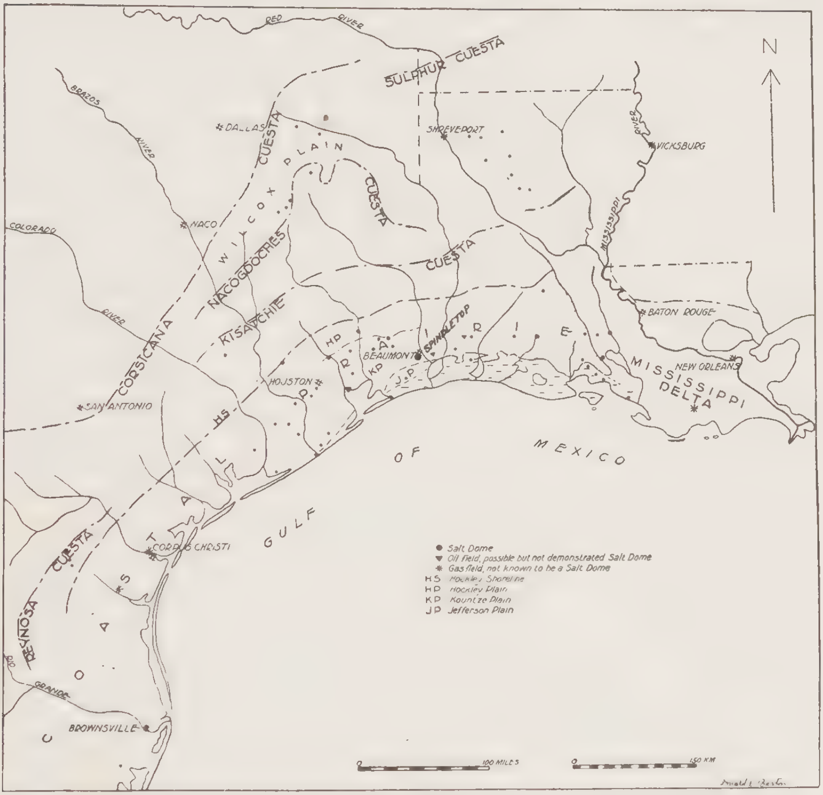

FIG. 1.—Physiographic map of the Texas-Louisiana salt-dome area showing the position of Spindletop.

PHYSIOGRAPHY

The physiographic province in which the salt domes of Louisiana and Texas occur is the Gulf Coastal plain (Fig. 1). In southeast Texas and northwest Louisiana, it is composed of the Coastal

Prairie, the Kesatchie Cuesta, and other cuestas farther inland. The character of this physiographic province is set forth and its component plains and scarps are described elsewhere by the senior author.[1]

The characteristic surface expression of the domes of the Coastal group which are marked in the topography is a mound of approximately the same diameter as the salt core, in shape very much like an inverted wash basin, with or without a central depression. The height of the mounds ranges from a few feet to 200 feet (60 m.). The salt-dome mound at Spindletop is one of the fainter type without a central depression, and it rises only some 10 to 15 feet above the general level of the Kountze plain, and 30 feet above sea-level. The mound is roughly circular in outline. On the north, east, and west sides, the mound slopes gradually and without break into the surrounding prairie. On the south side, there is a much steeper slope, which, however, seems to be due largely to the erosion of a shallow valley across the southwest edge of the dome. The mound is not as large areally as the salt core, but seems to coincide in position more with the cap rock, which covers only about two-thirds of the top of the salt.

GEOLOGY

Surface.—Spindletop mound is composed of sands which may be Lissie or Beaumont. The surrounding prairie is composed of clays, sandy clays, and clays of the Beaumont formation.

Subsurface.—Spindletop is a characteristic Gulf Coast salt dome, and as such is composed of a stock like core of rock salt, sedimentary beds dipping quaquaversally away from the salt core, and an anhydrite-gypsum-limestone cap on the top of the salt (Fig. 2).

The salt core is roughly circular in plan, and about 1 mile (1.6 km.) in diameter. It is delimited on the northeast by the Texas Company's McFaddin No. 1, which struck the salt at a depth of 2,579 feet (787 m.), the Gulf Production Company's McFaddin No. 2, and the Rycade Oil Corporation's No. 2 McFaddin, which were drilled, respectively, to depths of 3,278 feet (999 m.) and 4,162 feet (1,296 m.) without striking salt; on the southeast by the Gulf Production Company's No. 4 McFaddin which struck the salt at a depth of 1,684 feet (513 m.), and No. 3 which went to a depth of 3,780 feet (1,152 m.) without striking salt; and on the west by a well just west of the railroad track which went into the salt at a depth of 2,000 (?) feet (600 m.), and by Marrs McLean No. 1 which went to a depth of 3,700 feet (1,128 m.) without striking the salt. On the north, the edge of the salt has not been shown clearly by the drilling but on the basis of the symmetry of the surface mound, and of the rest of the edge of the salt, it seems probably to lie just south of the railroad crossing on the Beaumont road from the field.

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[1] Donald C. Barton, "Pine Prairie Salt Dome," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, to appear later.

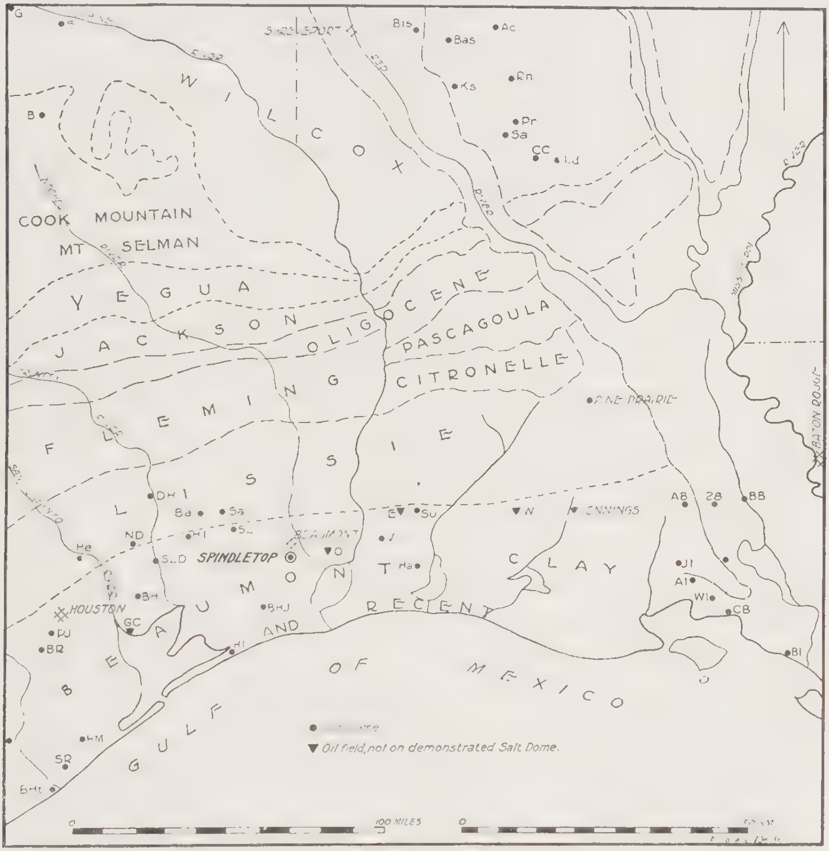

FIG. 2

The salt core has a relatively flat top and steep sides. In the center of the field, the top of the salt is found at depths of 1,200 to

1,600 feet (300 to 500 m.). The Iowa Beaumont well, drilled near the center of the dome, struck salt at 1,200 feet and was abandoned in it at 1,790 feet. In Higgins No. 2, drilled 2,000 feet north of the Iowa Beaumont well, the top of the salt was reported as at 1,647 feet (501 m.). On the east side, the Texas Company's No. 1 well struck salt at 2,579 feet and abandoned the well in it at 2,626 feet.

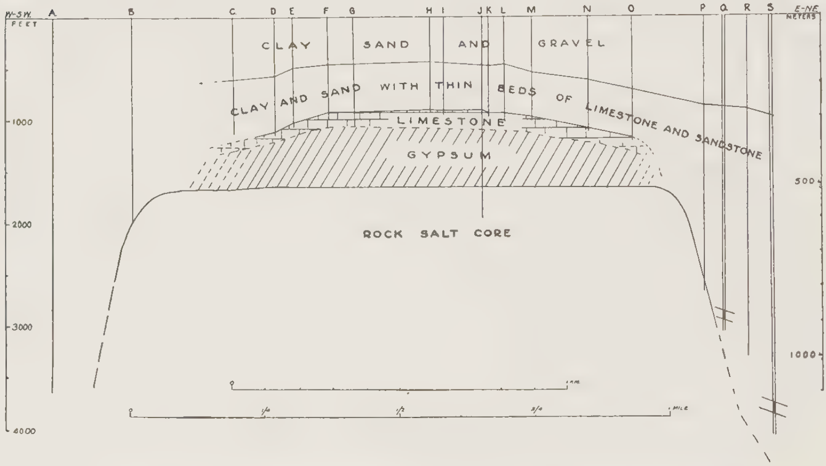

FIG. 3.—West-east section through the Spindletop salt dome (partly after Fenneman)

A = Marrs McLean, Gladys City No. 1
B = ?
C = Lucas No. 2
D = Guffey No. 2
E = Higgins No. 2
F = Beaumont Confederation No. 2
G = Robertson No. 2
H = Keith Ward No. 2
I = Heywood No. 2
J = Higgins No. 2
K = Heywood
L = National No. 1
M = National No. 2
N = Beaumont Pacific
O = Denver Beaumont
P = T. T. Co. No. 1
Q = Gulf Prod. Co., McFadden No. 1
R = Gulf Prod. Co., McFadden No. 2
S = Rycade Oil Corp., McFadden No 1

On the south, the Gulf Production Company's McFaddin No. 4 struck salt at 1,684 feet and abandoned the well at 1,787 feet. On the west, salt was struck at 2,000 feet. None of the salt wells have been so located as to give accurate data concerning the slope of the sides of the salt cores, but the differences between the depths at which the edge salt wells struck the salt, and the depths to which the wells not far out from the edge of the salt went without striking the salt, indicate that the slope must be steep (Fig. 3).

The cap at Spindletop is a disklike mass of anhydrite-gypsum and limestone (dolomite) which rests on the top of the salt but does not completely cover it. In the center of the field, in Higgins No. 3, the top of the cap was found at a depth of 886 feet (270 m.) and the cap was 761 feet (232 m.) thick; in Higgins No. 7, the top of the cap was found at a depth of 704 feet (214 m.). About 600 feet west of Higgins No. 7, in the Southern Company's No. 4, the top of the cap was encountered at 982 feet (298 m.) and 2,400 feet (720 m.) west at 1,210 feet (368 m.) About 2,500 feet (750 m.) north-northeast of Higgins No. 7, the top of the cap was at 1,095 feet (333 m.). In Higgins No. 2, 1,500 feet (450 m.) south of Higgins No. 7, the top of the cap was reached at 995 feet (303 m.). Toward the edge of the dome on the south and southwest, the cap seems to be missing. The cap, therefore, seems to be highest over the center and to slope away in all directions. As the top of the salt seems to be comparatively flat, the cap is apparently thickest in the center.

The anhydrite-gypsum portion of the cap is not well known. As is characteristic of the cap rock of the Gulf Coast salt domes, the anhydrite and gypsum form the lower part of the cap, and rest on the salt. Few of the wells were drilled through the limestone into the anhydrite and gypsum. The scanty data available in regard to them, are given by Hayes and Kennedy, and by Fenneman. As anhydrite is commonly reported as "gyp" by the drillers, the proportions between the anhydrite and gypsum are not known.

The limestone (dolomite) of the cap forms a cover extending over the anhydrite and by some is called "the cap" in contradistinction to which an anhydrite-gypsum cap is called "false cap." (Fig. 4). At the sulphur mines, the upper, barren portion of the limestone is called the "cap." Salt-dome geologists speak of the whole mass of exogenous rock capping the salt as the "cap." At Spindletop the limestone of the cap was identified in the early days as dolomite and has always been so designated. The following analysis of Spindletop cap rock, however, shows only a trace of magnesium, and the only sample of the "dolomite" from Spindletop that the senior writer has seen, as well as all the samples of limestone from the cap of other domes, effervesced in cold dilute hydrochloric acid. Much at least of the dolomite therefore seems to be limestone.

The most striking characteristic of the rock is its extreme porosity. During the gushing of wells, rock fragments varying in size from a fraction of an inch to the diameter of the casing have been blown to the surface. These always have a porous texture and even their most compact portions are shown, under the microscope, to contain a large proportion of vacant space. By the workers in the field the rock is compared to light-colored maple sugar. In addition to the minute spaces between the crystals, the rock itself contains many large cavities. The maximum size of these cavities cannot be determined, but many drillers report instances of the tools dropping several feet after passing through the outer crust of the rock. Considering the volume of oil recovered from the rock, the porosity must

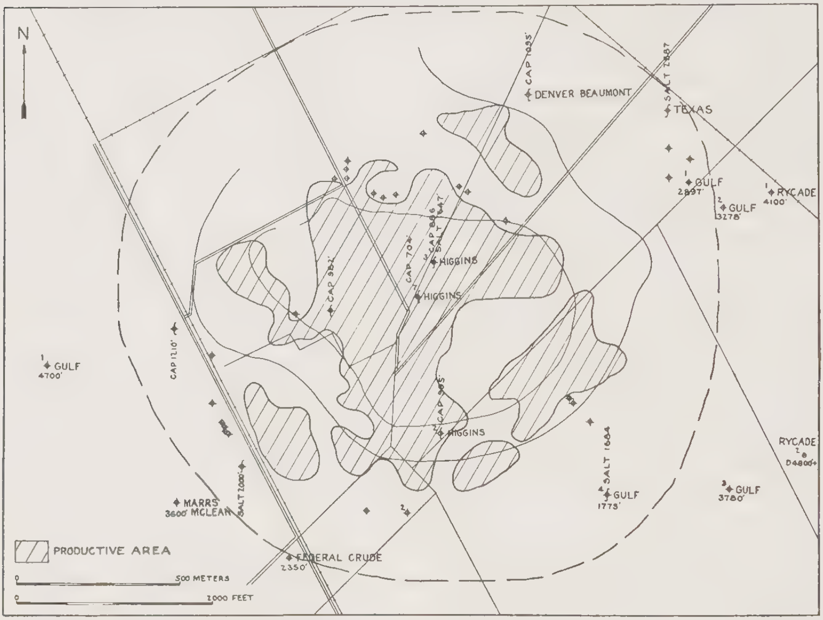

FIG. 4.—Map of Spindletop showing productive area, well data, contours on surface mound, and the − 3,000-foot (900 m.) contour on salt.

NOTE.—Rycade No. 2 marked as drilling at 4,800 feet has been abandoned at 5,400 feet, and the Rycade Oil Corporation has abandoned an additional dry hole at 3,962 feet, which should be about 1,400 feet north of the Gulf 4,700-foot dry hole.

exceed 33 per cent, or oil must have come in from an entirely unknown source. This high porosity combined with the high gas pressure explains the enormous yield of the early gushers.

Native sulphur is reported to be an important accessory mineral in the cap and in the beds immediately above the cap. In blow-outs and in gushers, large pieces of pure sulphur, crystals of sulphur an inch or more in length, chunks of mixed limestone and sulphur, and chunks of sulphur mixed with sand and clay have been blown out of the wells. In Heywood No. 3, sulphur rock was reported from four horizons, the lowest of which rests immediately on the oil rock. In a number of other wells, sulphur was reported in beds 5–45 feet (1½–13 m.) thick immediately above the oil rock. In those horizons, the sulphur was found mixed with sand, clay, or, in some cases, limestone. Some sulphur, the amount of which was not specified, was found in the oil zone, but not so much as below the oil zone. As few wells have been drilled below the top of the oil zone, not much is known in regard to the lower sulphur zones. In the sulphur domes, the main zone of enrichment is the zone of contact between the limestone and the anhydrite gypsum. The sulphur in the cap rock at Spindletop is reported to have been in the form of pure sulphur filling cracks and cavities in the rock and as crystals lining cavities in the oil-bearing rock.

TABLE I*

ANALYSIS OF SPINDLETOP LIMESTONE CAP ROCK

Silica	0.40
Oxide of iron Oxide of alumina	0.50
Lime	54.89
Magnesia	trace
Sulphur—as free sulphur and in organic combination	1.58
Sulphur—as sulphuric acid in combination	0.21
Carbonic acid	42.45
Total	100.03

*Analysis by S. H. Worrell, quoted by Fenneman, *U. S. G. S. Bull. 282* (1906), p. 27.

The beds surrounding the salt core and the cap consist predominantly of sands and clays and minor amounts of gravel, calcareous sandstone, and possibly a little limestone. On the top of the dome, the beds above a depth of 500 feet (150 m.) are composed almost entirely of sand and gravel, and the beds from this depth to the top of the cap are composed largely of clay, though "lime" is reported in beds 1–2 feet thick; in the Denver-Beaumont well, a 27-foot bed of lime was encountered that took seventy-five days to drill through. On the flanks of the dome, the upper zone of sand and gravel is 1,000 feet (300 m.) thick; between depths of 1,000 and 3,000 feet (300–900 m.) the section is composed predominantly of clay. Immediately below a depth of 3,000 feet, there are a few hundred feet of sand, sandstone, and calcareous sandstone below which are sands and clays. On the basis of lithology, a fair correlation of beds is possible across the dome and shows a gentle doming of the base of sand and gravel zone in conformity with the top of the cap. The wells on the flanks are so few and so scattered that it is not possible to work out the structure of the surrounding beds. From the Gulf Production Company's McFaddin No. 2 to the Rycade Oil Corporation's McFaddin No. 1 there is apparently a dip of about 50 feet in a distance of 500 feet. The base of the sand and gravel zone has suffered relative uplift of around 500 feet (150 m.) over the center of the dome in comparison to its position in the flank wells.

Stratigraphy.—The stratigraphic section as determined largely from the outcrop of the formations farther north is as follows:

The following section was found in the Rycade Oil Corporation's McFaddin No. 2:

Beaumont Clay
  Lissie
  Citronelle
Miocene
  Re-worked Cretaceous was identified from 1,800 to 3,915 feet (548 to 1,185 m.)
  Re-worked Cretaceous and re-worked Middle Oligocene at 3,932 feet (1,195 m.)
  No fossils in cores at 4,019, 4,057, 4,108, 4,128, 4,158, 4,166, and 4,172 feet
  Re-worked Cretaceous in cores from 4,187 and 4,211 feet (1,273 and 1,280 m.)
Non-fossiliferous zone with cores at 4,220, 4,230, 4,248, and 4,391 feet
Oligocene
  Discorbis zone at 4,508 feet (1,370 m.)
  Oligocene core at 4,694 feet
  Non-fossiliferous cores at 4,790 and 4,816 feet

The top of the Oligocene according to the section worked largely from the outcrop should lie at a depth of 1,300 to 1,400 feet (390 to 420 m.) In the Rycade Oil Corporation's McFaddin No. 2, the top of the Oligocene was actually at a depth of about 4,300 feet. Since in the position of this well beds at 4,300 feet should be much uplifted, the normal position of the top of the Oligocene should be at a much greater depth. The section above the Oligocene, therefore, shows a thickening of at least 3,000 feet (900 m.) and probably over 4,000 feet (1,200 m.).

TABLE II

Formation	Lithologic Character	Feet	Meters
Pleistocene Beaumont clay	Clay with silts and sands-marine	40	12
Pleistocene Lissie formation Pliocene Citronelle formation	Sands and gravels with some clay; non-marine chiefly	1,000 250	300 75
Miocene Pascagoula clay	Clays with a few lenses of sand and sandstone—Marine and non-marine	300	90
	Fleming Formation		
Oligocene Hattiesburg clay	Non-marine clays with thin layers of sand and sandstone	350	105
Catahoula sandstone	Non-marine sands, sandstones, clays, and fine conglomerates	475	142
Eocene Jackson formation	Marine marls, clays, and thin beds of sandstone	500	15
Yegua		800	240

ORIGIN OF THE DOME

Various theories have been advanced in the past to account for the formation of the salt domes. Among the American geologists not familiar with the more recent descriptions and discussions of the German and Roumanian salt dome, many of these theories still have considerable vogue. In the light of the knowledge now available in regard to the German and Roumanian domes,[1] and more especially the former, there seems to be little doubt that the salt domes are the result of plastic yielding of pre-existent sedimentary salt formations to deformation. In view of the slight knowledge actually in existence in regard to the salt of our American domes, it is not strange that distinct evidence of the sedimentary origin of the salt has not been observed. Many of the domes on which the drilling has been well placed show distinctly the great upthrust of the salt, as evidenced by the way it has dragged up the adjacent sediments with it. On account of the scattered spacing of the wells on the flanks of the dome, those relations are not well shown at Spindletop.

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[1] See Erich Seidl, "Preuss. Geol. Landesanstalt," *Archiv für Lagerstähenforschung*, Heft 26 (1921). The abundant sections illustrating this paper can be understood readily by persons familiar with only a few words of German.

ORIGIN OF THE CAP

The more probable alternative hypotheses for the origin of the cap are: (1) that it is sedimentary limestone which has been pushed up ahead of the rising salt mass and which has been largely altered by sulphate waters; (2) that it is sedimentary anhydrite which has been pushed up ahead of the rising salt mass; (3) that it is a secondary deposit resulting from the precipitation of calcium sulphate of vadose sulphate waters coming in contact with the highly saline waters surrounding the salt dome; (4) that it is residual material which has been left behind in the solution of the salt.

The cap of the German domes is rather generally held by the German geologists to be residual. This theory seems to be the least probable of the four for the American cap rock but it is not impossible. The evidence in regard to the origin of the cap rock of the American salt domes is rather conflicting. At Spindletop the thick disk-like cap, not completely covering, or projecting beyond the top of the salt, has the form, size, and position of a block uplifted by the salt. The absence of the cap on the southern edge of the dome would demand explanation, if the cap were a secondary deposit formed in place, or if it were a residual deposit formed in place. As the upthrust of the salt core well may have been periodic, the fact that the cap has been upthrust into its present position is not evidence that it did not form in place at greater depth.

AGE OF THE DOME

The upthrust of the salt core to form a salt dome presumably is a long slow process which extends through several geologic periods.

The deformation of the late Pleistocene plain indicates upthrust due to upthrust of the salt core or to hydration of the anhydrite of the cap of gypsum. The inrusion of the salt into the Miocene indicates that the salt itself is older than Miocene and that a part of the intrusion is later than early Miocene. The salt itself carries no evidence of its age, either at Spindletop or on any of the other domes. At some domes, as, for example, Damon Mound, it is possible to determine that much upthrust had taken place by the beginning of Miocene times, but at Spindletop no evidence is available in regard to upthrust before Miocene times. From anology with the other domes, it seems probable the upthrust began well before the beginning of Miocene times. On none of the domes is there recognizable evidence of the time of the first distinct upthrust.

OIL AND GAS

Indications.—The indications which led to the drilling at Spindletop were the mound, gas seeps, and sour waters. Although indistinct, the mound is and was a marked feature of its region. By placing a bottle over a gas seep and getting an accumulation of reduced sulphur, Captain Lucas demonstrated that the gas was in part at least sulphur bearing. The sour waters were found both in springs and in shallow wells. Oil seeps have been reported, but this report has been denied by men familiar with the field in its early days. Paraffine dirt was not reported, but was not known in the early days and, if originally present, would later have been obscured by the development.

Occurrence.—Gas was originally present in rather moderate amount in all the oil sands and in gas sand just above the main super-cap sand. The gas from this sand is said to have caused the most destructive blow-outs at Spindletop. Although blow-outs from various horizons were common, and although the gas was under great pressure, the amount of the gas in all cases was apparently small, as the blow-outs did not last many hours.

Oil was found pretty much through the lower part of supercap section and in the top of the cap. The first oil at Spindletop was obtained by Captain Lucas at 575 feet (172 m.). The main productive horizon in the super-cap beds was a sand lying at a depth of 710 to

850 feet (213 to 255 m.) and at a distance of about 120 feet (36 m.) above the top of the cap. This "sand" was neglected in the early days in the rush for the big production in the cap, and attention came to be paid to it only after the waning of that production. The main productive sand, the one from which most of the production of the field was obtained, was the top of the cap. The oil was contained in the pores of the porous limestone and in the fissures and caverns in it. The wells had to go only a short distance into the limestone to tap the oil. The top of the limestone was at a depth of around 900 feet (270 m.) below the surface in the center of the field, and 1,000 to 1,100 feet (300 to 330 m.) below the surface on the edge of the field. A considerable part of the production is still obtained from the cap. Although numerous shows of oil have been obtained from supercap sands, there has been little or no production from them, except that from the sand at from 710 to 850 feet (213 to 255 m.).

Character.—Most of the gas at Spindletop was a wet petroleum gas containing a large amount of hydrogen sulphide. The combination of H_2S and the petroleum vapor had a very poisonous effect on those inhaling it in even moderate quantities, and "gassing" of the oil-field workers was a common experience at Spindletop in the early days; some deaths occurred from the gassing, but in most cases the men were merely temporarily "knocked out," and came to themselves or were resuscitated. The eyes seemed particularly susceptible to the effects of the gas, and gassed eyes was a common and painful ailment of the oil-field workers. The gas from the gas sand was a dry gas and was of a harmless nature.

The Spindletop oil is a dark-green to brownish oil with a Baumé gravity of 21–23°. On refining it yields, according to Fenneman:

	Per Cent
Gasoline	1.8
Kerosene	17.1
Solar	15.4
Lubricating	52.2
Asphalt	7.5

A similar-appearing oil with a gravity of 22.2° Baumé was obtained from the Rycade Oil Corporation's McFaddin No. 1, at 3,895 feet (1,122 m.).

Production.—The total gauged production of oil from the Spindletop field to January 1, 1924, has been 47,091,054 barrels (7,195,780 metric tons). On account of wasteful handling and lack of storage in the early days, enormous quantities of oil were lost. The amount of oil thus not accounted for is impossible of accurate estimation, but must have been enough to bring the figure for the total production of the field to well over 50,000,000 barrels (7,500,000 tons) (Fig. 5). The figures for the total yearly gauged production of the field are as follows:

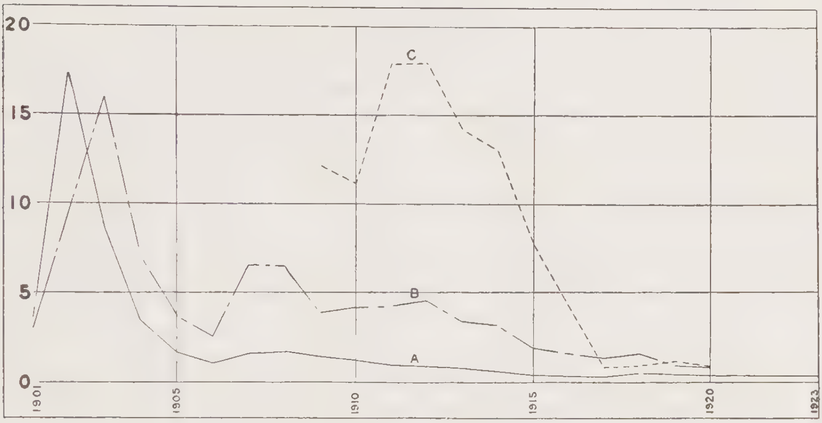

FIG. 5.—Production curves of Spindletop Oil Field.

A, yearly production of field in millions of barrels:

B and C, yearly production, respectively, of two leases in hundred thousands of barrels.

	Barrels Net	Metric Tons
1901	3,593,113	538,750
1902	17,420,949	2,612,100
1903	8,600,905	1,289,620
1904	3,433,842	514,870
1905	1,600,379	239,960
1906	1,075,755	151,300
1907	1,615,513	242,230
1908	1,747,537	262,030
1909	1,388,170	208,140
1910	1,182,436	177,290
1911	965,939	144,830
1912	822,916	123,390

(Continued on page 494)

	Barrels Net	Metric Tons
1913	716,374	107,413
1914	580,130	86,985
1915	388,266	58,217
1916	340,441	51,046
1917	308,039	46,187
1918	502,265	75,310
1919	458,680	68,774
1920	323,995	48,580
1921	321,080	48,143
1922	295,015	44,235
1923	309,315	46,379
Total	47,991,054	7,195,779

It is interesting to notice that of the production 63 per cent was produced in the first three years of the life of the field. Spindletop's production of 17,420,949 barrels (2,612,100 tons) in one year has been exceeded in the Gulf Coast only by Humble, which produced 18,066,428 barrels (2,708,850 tons) in 1905.

The yearly production of representative leases has been, respectively, as follows:

	Barrels Net	Metric Tons
1901	299,579	44,920
1902	852,229	127,780
1903	1,604,884	240,640
1904	708,246	106,190
1905	370,388	55,540
1906	255,574	38,320
1907	657,326	98,560
1908	646,825	96,980
1909	390,569	58,560
1910	423,035	63,430
1911	422,726	63,380
1912	456,854	68,350
1913	337,035	50,530
1914	313,620	47,020
1915	192,870	28,920
1916	163,390	24,500
1917	142,390	21,350
1918	156,601	23,480
1919	94,323	14,140
1920	85,085	12,760
Total	8,572,550	1,285,364

	Barrels Net	Metric Tons	Wells
1909	12,136	1,820	2
1910	11,151	1,670	2
1911	17,813	2,670	2
1912	17,943	2,690	2
1913	14,270	2,140	2
1914	12,998	1,950	2
1915	7,890	1,180	2
1916	4,287	640	2
1917	844	137	2
1918	972	146	2
1919	1,216	182	2
1920	901	135	2
Total	102,420	16,460	

1906	19,221	2,880	4
1907	58,805	8,820	6
1908	26,210	3,930	4
1909	43,964	6,590	4
1910	30,139	4,520	4
1911	18,831	2,820	3
1912	8,926	1,340	3
1913	4,110	620	2
Total	210,207	31,520	

The per acre production at Spindletop is one of the highest for the Gulf Coast. The very sharply delimited productive area amounts to 265 acres. With a total production to date of fifty million barrels, the per acre production for the whole field is 190,000 barrels (28,500 tons). The average per acre production for the better fields on the Gulf Coast is about 50,000 barrels (7,500 tons), but in the case of most of the fields, the total productive area includes considerable territory of very poor productivity, and if in these cases only the main productive area is considered, the per acre production is much higher. The per acre production for the old or SE field at West Columbia up to January 1, 1921, was 123,000 barrels (18,400 tons) and, on the basis of the writers' estimate at that time of the future production, the ultimate per acre production of the SE field would be of the order of 200,000 barrels (30,000 tons). The per acre production at Jennings has been 209,000 barrels (31,340 tons) for the whole productive area and 306,000 barrels (45,880 tons) for the main productive area. Of the other Gulf Coast fields the shallow or cap rock field at Humble is the most similar to Spindletop. The total cap-rock production there has been about the same as at Spindletop, but the productive area is seven times as great and the per acre production is only 30,000 barrels (4,500 tons).

The total number of wells drilled has been about 2,050, or on the average of about six wells per acre. Spindletop holds the record for the Gulf Coast Oil fields and for the oil fields of the United States for gusher production. The production of the Lucas No. 2 (the Lucas gusher) was variously estimated at 75,000 to 125,000 barrels (11,250 to 18,740 tons) per day. That of the Heywood Brothers No. 2 was estimated at 96,000 barrels (13,490 tons) per day. By gauge of its flow into a tank, it is said to have flowed 8,000 barrels (1,200 tons) in two hours. Within ten months it had produced 1,395,000 barrels (209,200 tons) of oil. There were only these two enormous gushers, but in addition to them there were many large wells. Although the data in regard to the early wells is very scanty, it is known that the Guffey and Gailey Oil Company completed five large wells on their Gladys City lease with initial production as follows: No. 7—15,000 barrels (2,250 tons), No. 4—10,000 barrels (1,500 tons), No. 1—8,000 barrels (1,200 tons), No. 5—7,000 barrels (1,050 tons), No. 9—5,000 barrels (750 tons); that the Beaumont-Palestine Oil Company completed a 10,000 barrel (1,500 tons) well; and that the Hogg Swayne, the American Oil Company, and other companies completed big wells.

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THE BIG HILL SALT DOME, JEFFERSON COUNTY, TEXAS

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ABSTRACT

Although salt has not been penetrated in drilling, the Big Hill salt dome, Jefferson County, Texas, in all probability is a characteristic Gulf Coast salt dome. It has a very distinct salt-dome mound, a characteristic salt-dome cap. One well has been completed as a producer. The oil is typical Gulf Coast crude.

LOCATION

Big Hill is in the southwestern part of Jefferson County, Texas, about 12 miles from the Gulf of Mexico. It is most easily reached by train or automobile from Beaumont. The Gulf, Colorado & Santa Fe Railroad passes through Hamshire, 11 miles northwest of the "Hill." All freight and supplies come to Hamshire by rail and are hauled in by wagon or truck during dry weather. During wet weather the road is almost impassable.

HISTORY

Record of the early history of the development of Big Hill is very unreliable. Little was written about it during the period of early exploration, and all that can be learned from men who were more or less in touch with the development is contradictory.

It appears that the first well was drilled by the J. M. Guffey Company in 1901 on the southeast side of the mound. This well hit cap rock at 370 feet and continued in it to its total depth of 1,600 feet. Oil showings were found at several horizons, but they were not strong enough to produce. Shortly after this well was completed, the Texas Oil Fields Ltd. Company entered the field and drilled three wells. One of these wells was near the J. M. Guffey well, and the other two were north of the mound. Neither of the later wells found anything but unconsolidated material to their total depth, which was 2,600 and 3,000 feet, respectively.

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[1] Chief geologist, Houston Oil Company.

The Big Hill Mound seems to have been neglected for a number of years, until about 1913, when an association headed by S. W. Pipkin, a large landowner in this district, drilled a well on the northeast flank to a depth of 1,675 feet. This well was abandoned in a porous rock, but had several showings in sands above the rock. Encouraged by these showings, the Texas Exploration Company and the Texas Company started development at about the same time. The Texas Exploration Company drilled four wells on the top of the dome and its south flank, and the Texas Company drilled two wells off of the south flank. All of the Texas Exploration Company wells struck cap rock and were abandoned at shallow depths; the deepest went to 1,385 feet. The wells of the Texas Company were drilled to 3,505 feet and 2,922 feet, respectively, and neither encountered either cap rock or oil in commercial quantities.

In 1921 the Houston Oil Company, of Texas, took leases covering the south half of the hill. To date, twelve wells have been drilled—ten on the southeast side of the dome and two on the west side. Of the wells drilled on the southeast side, three have been abandoned in porous rock, one completed as a producer, and the others abandoned at various depths down to 4,049 feet. Both the wells drilled on the west side have been abandoned in cap rock. The well which was finished as a producer came in September 1, 1923, making 400 barrels per day of clean oil. Water soon began to come in and the well declined rapidly. At the present time it is producing 30 barrels of 19.5° Baumé gravity oil per day and about 200 barrels of water. This oil is the typical Gulf Coast green oil with high lubricating oil content.

During 1923 a well was drilled on the east side of the dome by the Gulf Production Comapny to a depth of 4,780 feet. At the present time the Houston Oil Company has two rigs running on the west side of the Hill.

GEOLOGY

Big Hill is superimposed on a low ridge which is evidently an old shoreline and can be traced for many miles both east and west of the mound. This ridge has a uniform elevation of about 10 feet above sea-level, while Big Hill rises to an elevation of 35 feet on the north side and 31 feet on the south with a shallow saddle between the two points of greatest elevation.

Because of the small amount of drilling which has been done, the only cross-section available is across the south side of the hill along the line *A–B* (Fig. 1). This section is made with the top of the cap rock as control.

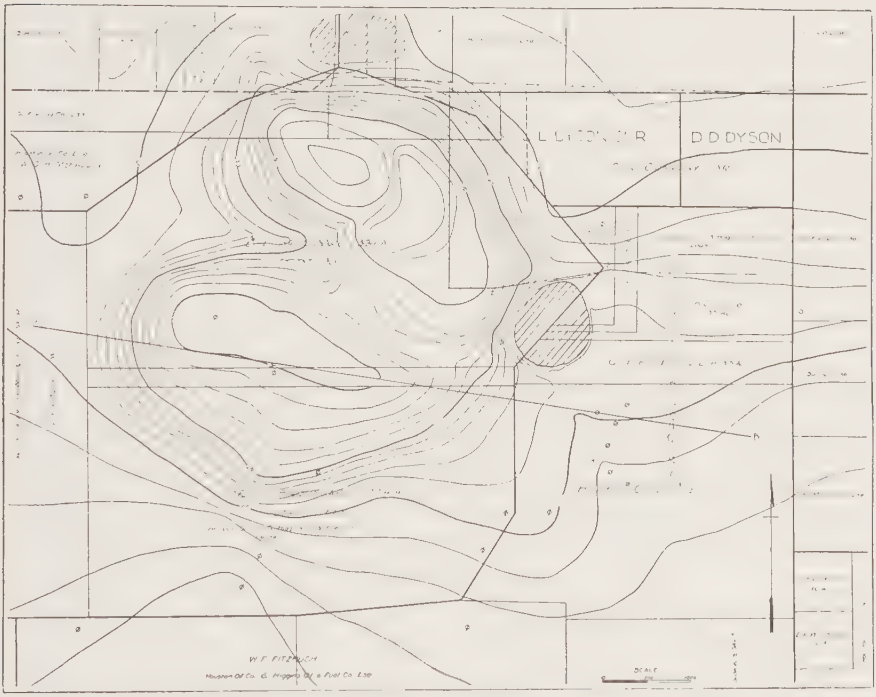

Fig. 1—Map of Big Hill salt dome

Although no salt mass has been found in any of the wells, it is reasonable to suppose that there is such a mass underlying the cap rock. The cap rock here is composed of a porous dolomitic limestone, gypsum, anhydrite, and a very porous limy sandstone which lies on the outer edge of the cap. It is very similar to that above known salt masses. Along the line *A–B* the cap rock has a known width of 6,000 feet, its west edge being still undetermined.

The cap dips at a very high angle on the east side, while on the west it has an apparent dip of about 30° (Fig. 2). From this and the shape of the surface elevation we are of the opinion that the thrust of the salt mass came from the west or southwest and swung to the north with a fracture through the saddle between the two points of greatest surface elevation. The lateral beds on the southeast side seem to be very badly fractured, while on the west they are fairly regular. Fossils from a depth of 3,270 feet in Pipkin No. 4 have been classified as Fleming in age.

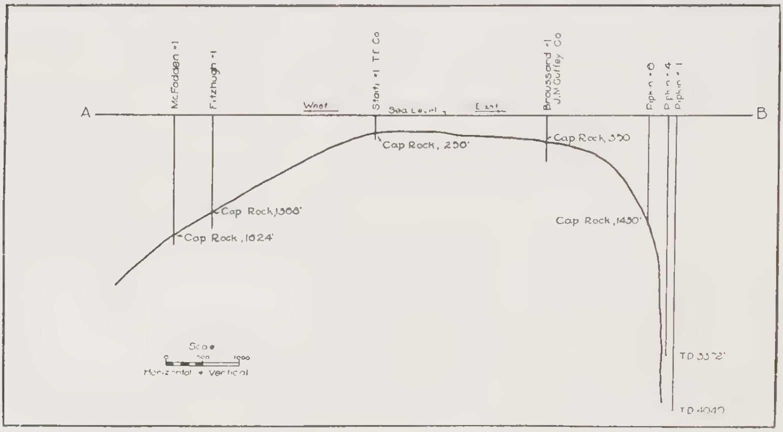

FIG. 2—Cross-section along line A-B of Figure 1

THE SARATOGA OIL FIELD, HARDIN COUNTY, TEXAS[1]

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ABSTRACT

Although the salt has not been drilled into, the presence of a typical cap-rock mass of anhydrite and gypsum capped by "lime" rock indicates that Saratoga is a salt dome. The cap rock is elliptical in plan with its major axis about 1½ miles in length and northeast-southwest in strike. The beds penetrated in drilling range in age from Jackson (Eocene) to Pleistocene. The oil is found on a series of lensing supercap sands. Oil was first produced thirty years ago from a shallow well and used for medicinal purposes. The real discovery of the oil field followed shortly after the discovery of Spindletop. The production reached a maximum of 3,000,000 barrels in 1903, and on account of the successive discoveries of new "sands" has fallen off moderately slowly. The crude oil is an 18° Baumé oil with a high content of lubricant stock but also with a rather high content of sulphur. Dates are given in regard to production methods and costs.

D. C. B.

INTRODUCTION

Location.—The Saratoga oil field is located in Hardin County, Texas, about 50 miles northwest of Beaumont. It is reached by a branch of the Gulf, Colorado & Santa Fe Railroad extending 10 miles south from Bragg, a station located on the main line between Beaumont and Somerville. Saratoga is about 13 miles slightly west of north of the Sour Lake field, and about 7 miles northeast of the Batson field.

History.—Attention was first attracted to Saratoga as a possible oil field because of surface indications similar to those at Sour Lake. The sulphureted and sour waters at Saratoga were considered very beneficial to the health in the early days, and people came in considerable numbers in the summer time to drink them. Gas seepages had been noted here for years, as had also seepages of oil. Fenneman[2] states that there were at Saratoga "certain spots in which the soil is impregnated with asphaltic substance."

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[1] Published by permission of E. T. Dumble, consulting geologist, Southern Pacific Co., Houston, Tex.

[2] N. M. Fenneman, *U. S. Geol. Survey Bull. 282*, p. 58.

The first well at Saratoga of which we have record was located just southwest of the center of the J. F. Cotton tract. It is interesting to note that this well was about in the center of the present productive pool. It was drilled with very primitive tools but actually produced a small amount of oil by bailing, the oil being used for medicinal purposes. In 1896 Savage Brothers became interested in Saratoga and drilled a well to a depth of 250 feet near this first well, obtaining a small amount of water and oil. Later, W. P. Conroy started a well about ½ mile to the south, but the tools became stuck at 120 feet and he was forced to abandon the test. Savage Brothers drilled several shallow wells with cable tools in the southwestern part of the J. F. Cotton tract between 1896 and 1900, but without any pronounced success.

After the bringing in of the Spindletop pool in 1901, interest was renewed in Saratoga and considerable drilling was done. The Saratoga Oil and Pipe Line Company completed their No. 1 Hooks (Rio Bravo Oil Company No. 200), at a depth of 995 feet, with an estimated production of 500 barrels. This well was located near the middle of the north line of the J. F. Cotton 157-acre tract. Their No. 2 Hooks (Rio Bravo Oil Company No. 201), was drilled to 1,600 feet, and brought in as a producer at a depth of 700 feet. The well was located near the site of the Savage Brothers' drilling. The holdings of the Saratoga Oil and Pipe Line Company, comprising all the land on the B.B.B. & C. survey No. 132, R. Teel, J. F. Cotton, and 93.69 acres of the C. F. S. Jordit survey, were taken over in 1903 by the Rio Bravo Oil Company.

During 1903 intensive exploitation took place in the vicinity of the northwest and southwest corners of the J. F. Cotton tract. During this year the field is credited with a production of 150,000 barrels of oil. The principal operators in the field at this time were Producers Oil Company (The Texas Company), J. M. Guffey Petroleum Company (Gulf Production Company), Rio Bravo Oil Com-Company (Southern Pacific Company), and the Santa Fe Railway Company. Up to August, 1904, some $200,000 had been spent in drilling and the field production had seldom been over 1,500 barrels per day. At about that time, a rich sand was discovered at a depth of about 1,500 feet in a well drilled by the J. M. Guffey Petroleum Company on the Greer tract in the northwest corner of the C. F. S. Jordit survey. The Producers Oil Company brought in their No. 4 for 10,000 barrels per day, and the Austin Oil Company brought in their No. 1 Moore for 12,000 barrels per day. In May, 1905, the Rio Bravo Oil Company brought in their No. 222 Cotton for an initial production of 3,700 barrels per day. As a consequence of the development following upon the bringing in of these large wells, the production for 1905 amounted to almost 3,000,000 barrels, the largest production for any year in the history of the field. For a short time in the early part of 1905 the daily production at Saratoga amounted to 20,000 barrels per day. In February, 1905, salt water began to show in the large wells and the daily production slumped to less than 10,000 barrels per day. With the exception of the large wells completed in 1904–5 it might be said that the average completion at Saratoga is a small well, seldom good for more than 400 barrels per day.

The production at Saratoga gradually fell off until in 1911 it was less than 1,000,000 barrels. In 1912 a good sand was developed at about 1,200 feet in the northeast part of the C. F. S. Jordit No. 1 survey, and an active drilling campaign ensued. As a consequence, the production for 1912 rose to 1,100,000 barrels. The production of the field gradually declined from 1912 to 1917, during the last year of which period but 683,000 barrels were produced. In 1918 new production was discovered in the extreme northwest corner of the Nancy Fuller survey and southwest corner of the R. Teel tract. This production, which came from around 1,900 feet in depth, raised the 1918 production to 790,000 barrels. In the latter part of 1920 and early part of 1921, production was developed by the Sun Company, Gulf Production Company, and Weldon Oil Company from a shallow sand (600–800 ft.) in the Mary E. Hopkins No. 1 survey just west of the northwest corner of the J. F. Cotton tract. This caused a drilling boom which increased the 1921 production to 936,000 barrels. The various booms at Saratoga can be noted very clearly on the yearly production curve shown in Figure 1.

In December, 1923, drilling activity at Saratoga was at its lowest

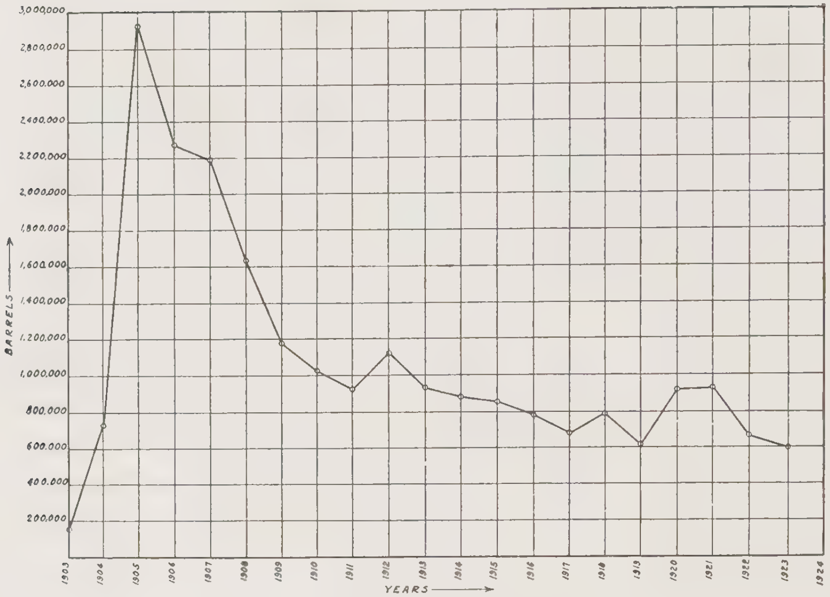

FIG. 1.—Yearly production, Saratoga field

ebb; only two rigs were running in the field; and the daily production had fallen off to 1,500 barrels per day divided as follows:

	Barrels
Rio Bravo Oil Company	600
Sun Company	320
Gulf Production Company	100
Paggi Brothers	170
Weldon Oil Company	140
Regna Oil Company	70
Miscellaneous	100
Total	1,500

The production for 1923, 603,000 barrels, was the lowest in the history of the field.

GEOLOGY

The Saratoga field is on the outcrop of the Columbia sands, as mapped by Kennedy. As shown by the accompanying map (Fig. 2), the total amount of relief within the field is about 40 feet. The surface is considerably dissected by drainage from Pine Island Bayou to the south and Black Creek to the north. As topographic relief of 40 feet is not uncommon in the area of Columbia sand outcrop, it is doubted if the topography has much relation to the subsurface dome. It is also to be noted that the highest part of the field, topographically, is about 3,000 feet slightly north of east of the highest elevation of the dome.

The soil in the Saratoga field is very sandy, and the surface was heavily forested at the time oil was first discovered. The timber has been removed, for the most part, as the drilling has proceeded.

Underlying the Columbia sands which outcrop at Saratoga are the Lafayette sands and gravels. For the most part these are fresh-water sands, and boiler feed water is obtained from them down to 500 feet. As the Beaumont clays are not found at Saratoga, the ratio of sand to clays penetrated is much higher than in almost any other field on the Gulf Coast.

The geological formations penetrated at Saratoga are as follows:

	Thickness in Feet
Pleistocene	
Columbia sands. Gray sand and gray and brown mottled sandy clays	100–150
Pliocene?	
Lafayette. Sands and gravels. Coarse "rice sands" and fine gravel with some clayey layers. Formation carries good grade of fresh water where underlying salt water has not been allowed access to it by drilling. Locally cemented into hard sandstone	400–1,300
Miocene	
Fleming equivalent. Blue gumbo and shales with sand and shale development locally. Sands are gray colored and medium fine grained. Fossil sea shells and Foraminifera found in this formation classify it as Miocene in age and either the time equivalent of the Fleming formation or slightly older	700–1,200
Oligocene	
Series of green-gray and lavender shales and gumbos and sandy shales in Gulf Production Company No. 2 Teel and Rio Bravo Oil Company B-83 have been classified on paleontologic evidence as Oligocene. Also black shales have been encountered in a few instances in Saratoga wells. Such shales from 1,910 feet in Rio Bravo Oil Company No. B-25 have been classified as Oligocene	200–700

EOCENE

Jackson sandstones. Jackson fossils are reported as having been found in cores taken from Rio Bravo Oil Company well No. 218.* The records giving the depth at which they were found and the name of the forms have been lost and we are unable to give complete details.

* *Trans. A.I.M.E.*, Bull. 104 (1915), p. 1632.

Saratoga is a rather deeply buried dome. The highest point on the cap rock is about 1,500 feet below the surface. Saratoga is a large, rather broad, flat dome with gently dipping sides (Fig. 3). The dome is roughly elliptical in shape with its longer axis extending in a general northeast-southwest direction. At a depth of 2,000 feet, it is 1½ miles across along the longer axis. The dip on the cap rock from the center of the dome outward, as shown by the cross-sections, is flat—as nearly as can be measured about 10° to the northeast and about 9° to the southwest. With the possible exception of occurrence of Jackson fossils rather high in one well, the drilling to date has failed to give any evidence of faulting on the sides of the dome, but it is possible that such faulting does exist to the northwest or to the extreme southeast. The logs of the few deep wells which have been drilled on the edge of the dome show conclusively that the dip of the cap rock becomes much steeper after the 2,700-foot contour is crossed. This is well shown in the cross-sections (Fig. 4).

The Saratoga dome is very peculiar in some respects. In only one well, the Sun Oil Company No. 134 McShane, in the extreme northeastern part of the field, has rock salt been logged. Mr. R. W. Pack,[1] manager of the Sun Company, states that although the formations were very salty, it is not definitely known that rock salt was encountered as no cores were taken.

Well No. 259 Jordit, of the Rio Bravo Oil Company, logs limestone and rock from 1,555 to 1,758 feet, a total thickness of over 200 feet. Professor W. F. Cummins has informed the writer that the cuttings from this well consisted principally of anhydrite and selenite. In the contouring of the dome, the top of the thin limestone cap overlying the anhydrite is taken as the top of the dome. This surface is irregular and in some instances might take in sandstone

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[1] Personal communication.

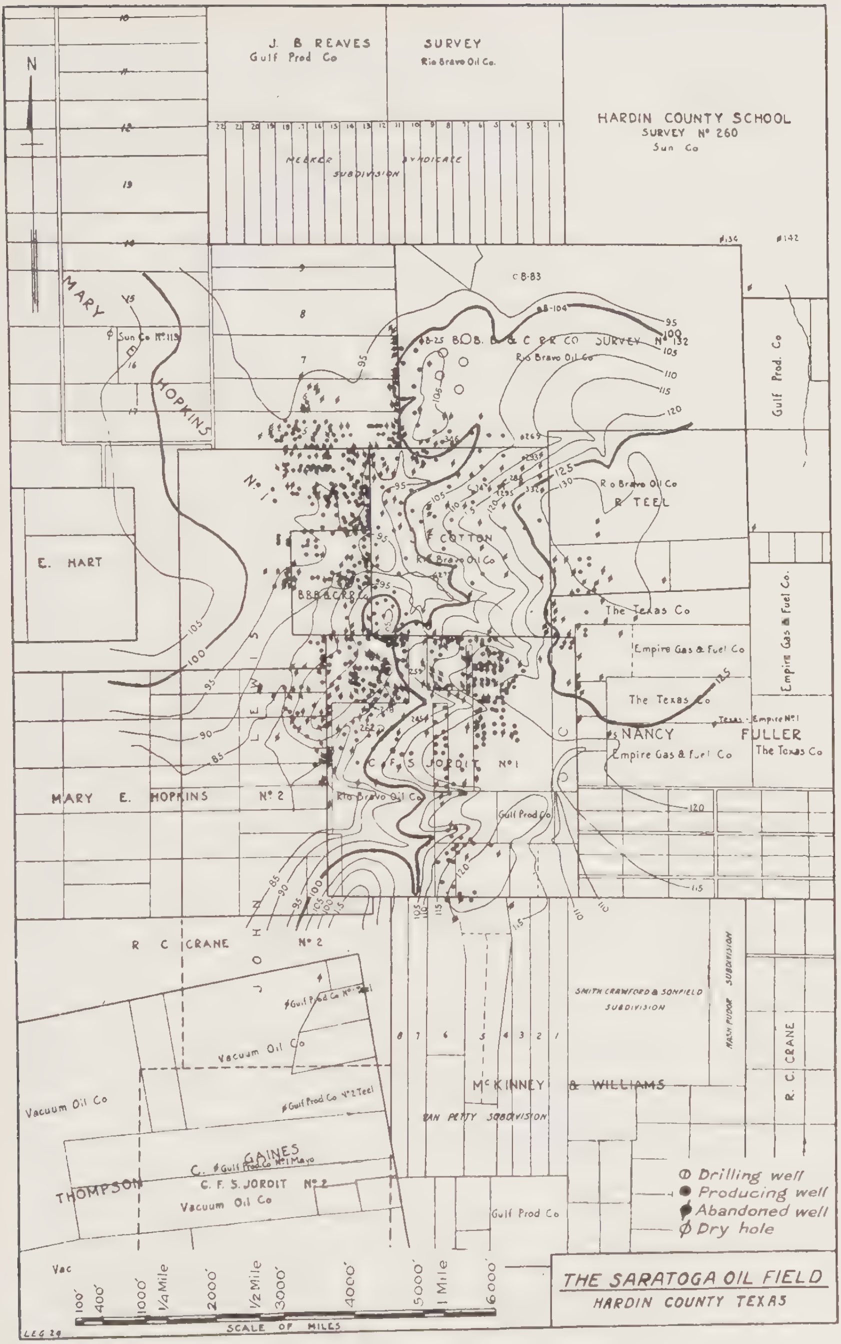


FIG. 2.—Topography, Saratoga field

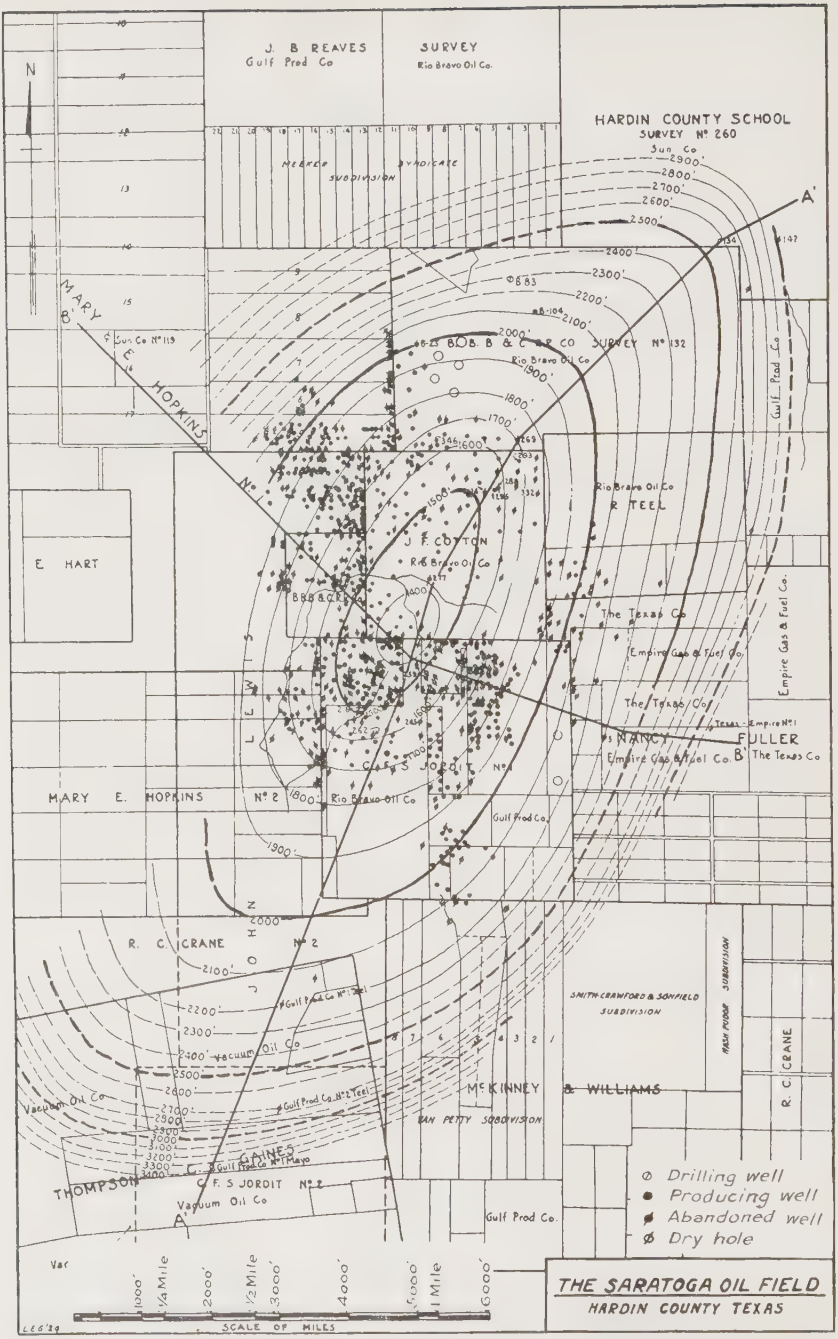
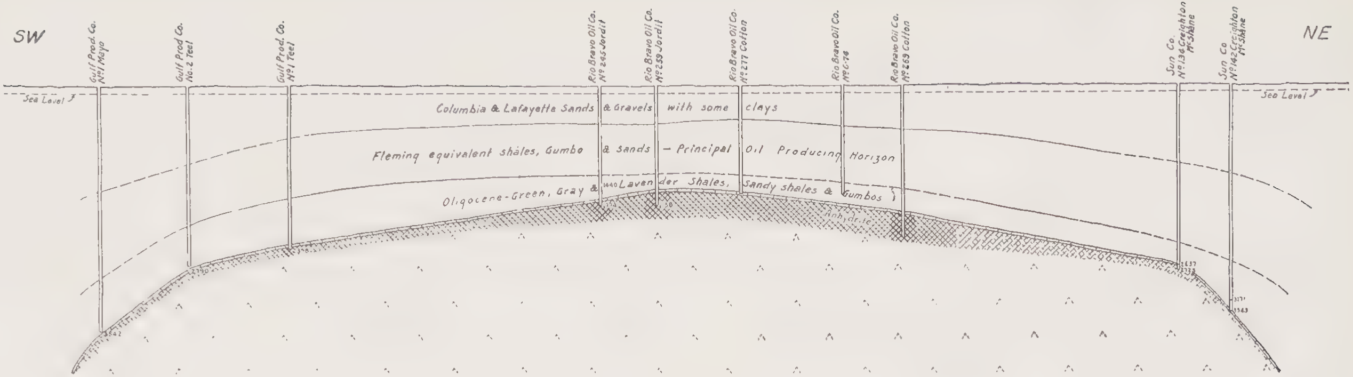
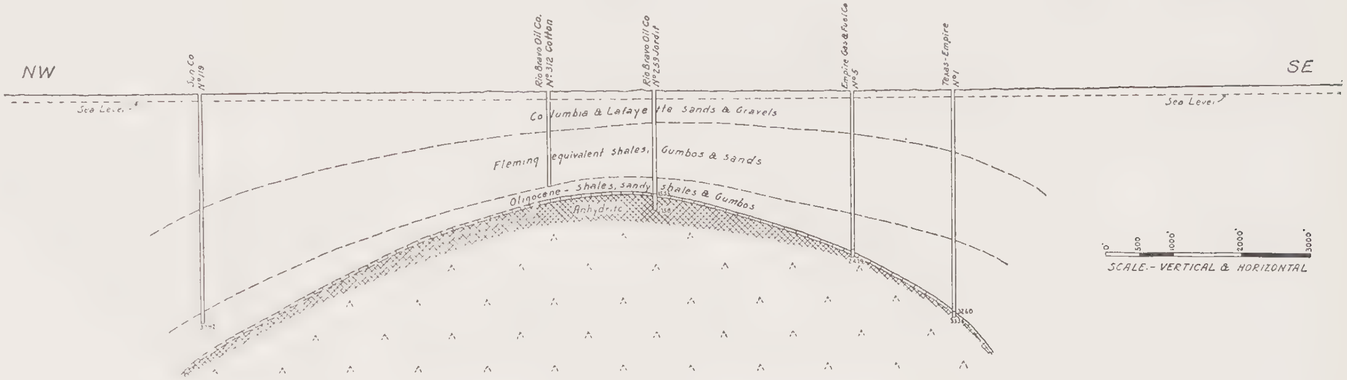


FIG. 3.—Contours on cap rock, Saratoga field. Contours based on elevation below sea-level.


SW
NE
Gulf Prod. Co. No1 Mayo
Gulf Prod Co. No. 2 Teel
Gulf Prod. Co. No1 Teel
Rio Bravo Oil Co. No 245 Jordit
Rio Bravo Oil Co. No 259 Jordit
Rio Bravo Oil Co. No 277 Cotton
Rio Bravo Oil Co. No C-74
Rio Bravo Oil Co. No 269 Cotton
Sun Co. No 136 Creighton-McShane
Sun Co No 142 Creighton McShane
Sea Level
Columbia & Lafayette Sands & Gravels with some clays
Fleming equivalent shales, Gumbo & sands - Principal Oil Producing Horizon
Oligocene-Green, Gray & Lavender Shales, Sandy shales & Gumbos
Anhydrite
1440
2790
3542
3637
3171
3543

SECTION A'-A'


NW
SE
Sun Co No 119
Rio Bravo Oil Co. No 312 Cotton
Rio Bravo Oil Co No 259 Jordit
Empire Gas & Fuel Co No 5
Texas-Empire No 1
Sea Level
Columbia & Lafayette Sands & Gravels
Fleming equivalent shales, Gumbos & sands
Oligocene - Shales, sandy shales & Gumbos
Anhydrite
2419
3260
3142
0
500
1000
2000
3000
SCALE.- VERTICAL & HORIZONTAL

SECTION B'-B'

FIG. 4.—Cross-sections of Saratoga salt dome

layers which have become cemented with lime. There is evidence that the limestone cap is thicker in the center of the dome than on the edges. Well No. 332 Cotton, of the Rio Bravo Oil Company, had anhydrite from 1,918 to 2,061 feet and very little limestone. Well No. 269 B.B.B. & C., of the Rio Bravo Oil Company, had about 45 feet of limestone (1,870–1,915 ft.), and then penetrated anhydrite for about 300 feet (1,930–2,224 ft.). Although rock salt is not known actually to occur under the limestone and anhydrite, it is assumed to be there. The thickness of limestone and anhydrite overlying the salt is possibly much greater than in the average dome.

The Columbia-Lafayette sands and gravels covering and surrounding this dome are supposed to lap up on the edge of it and to have a pronounced thickening from the center of the dome outward. The Fleming beds are about 700 feet thick in the center of the field but appear to thicken to about 1,200 feet on the edges. The Oligocene beds thicken from about 200 feet at the center to about 700 feet on the edges.

A considerable fauna of macroscopic fossils has been obtained from certain of the wells drilled at Saratoga. The Miocene has a fairly good invertebrate fauna in the northern part of the field, and Miocene vertebrate remains have been recovered from the southern part of the the field. The Miocene formations penetrated by the drill have yielded a fairly good foraminiferal fauna. The Oligocene has yielded a good foraminiferal fauna but few macroscopic forms. Species found in the various wells are as follows:

FOSSILS FROM WELL NO. 346 B.B.B. & C—RIO BRAVO OIL COMPANY

From a depth of 922–1,000 feet
  Divaricella? chipolano, Chipola
  Corbula radiatula, Oak Grove
  Lucina crenulata, Oak Grove
  Arca, close to an Oak Grove species
  Cancellaria, quite close but not identical to an Oak Grove species
  Nassa? sp.
  Terebra sp.
  Actaeon sp.
  Natica cf. *canrena*
  Terebra cf. *dislocata*
  Turritella subgrundifera, Chipola

From a depth of 1,040–80 feet
- *Corbula* n. sp., not Galveston well species or Oak Grove
- Fragments of *Chione*, possibly *C. glyptocyna* from Oak Grove
- Fragments of *Arca*, *Strigillia*, *Divaricella*, and *Phacoides*
- *Chama*, may be Oak Grove species
- *Turritella* fragment cf. *T. subgrundifera*, Oak Grove
- *Phacoides* cf. *sphaeriolus* Dall, Chipola

FOSSILS FROM WELL NO. 293 COTTON—RIO BRAVO OIL COMPANY

From a depth of 1,140–59 feet
- *Astarte* sp.
- *Turritella* sp.
- *Cardium* sp.
- *Divaricella*, 2 sp.
- *Chione* fragment

From the list it appears that these beds are of Lower Miocene age.

- *Strigillia* sp.
- *Corbula* cf. *swiftiana*
- *Lucina*, close to *L. crenulata*
- *Donax* sp.
- *Cerithium?* sp.
- *Solarium?* sp.
- *Chione*, worn sp. cf. *C. glyptocyna*, Oak Grove

This fauna also appears to be equivalent in age to the Oak Grove. Determinations by Mrs. Dorothy K. Palmer, in the Rio Bravo Oil Company laboratory.

VERTEBRATE REMAINS FROM WELL NO. 262 JORDIT—RIO BRAVO OIL COMPANY

Bones obtained between 400 and 600 feet
- Lower molar fragment of protohippine horse probably *Hipparion* or *Protohippus*
- Shaft of femur of *Merycodus*
- Ungual phalanx, compares closely with *Hipparion lenticulare* Cope
- Lumbar vertebrae of horse (?)
- Fragment of turtle shell
- Jaw fragments probably rhinoceros or camel

This material resembles very much the vertebrate remains obtained on the outcrop from the Fleming formation.

FORAMINIFERA FROM WELL B-83 B.B.B. & C.—RIO BRAVO OIL COMPANY

From a depth of 1,898–1,907 feet

Anomalina n. sp. (*taylorensis*)[1]
Pulvinulina n. sp. (*saratogaensis*)[1]
Frondicularia n. sp. (*saratogaensis*)[1]
Vaginulina n. sp. (*saratogaensis*)[1]
Vaginulina n. sp. (near *bradyi*)[1]
Discorbis n. sp. (*saratogaensis*)[1]
Nodosaria n. sp.
Nodosaria cf. *vertebralis*
Globigerina dubia? var.
Textularia globulosa? var.
Pulvinulina n. sp. (*hardini*)[1]
Cristellaria n. sp. (*saratogaensis*)[1]

The foregoing fauna has been placed as Miocene by Mrs. Esther Richards Applin because of its stratigraphic position, overlying the Oligocene found below, and because of the absolute difference in the faunas found, probably indicating a considerable time-break between their deposition.

From a depth of 2,177–87 feet

Discorbis bertheloti var.
Amphistegina lessoni var.
Truncatulina americana var.

According to Mrs. Applin, these forms are common to and characteristic of the uppermost or *Discorbis* zone of the Middle Oligocene.

FOSSILS FROM 2,060 TO 2,093 FEET IN GULF PRODUCTION COMPANY—TEEL NO. 2

Cytheritsis cf. *ashermani*
Nonionina scapha
Globigerina bulloides var.
Amphistegina lessonii (young)
Polystomella sp.
Pulvinulina texana
Nonionina scapha var.
Truncatulina americana var.

These are classified by Mrs. Applin as of Oligocene age.

Peculiar concretions from Saratoga wells.—A considerable quantity of oölitic barite has been bailed from certain Saratoga wells. It is described by E. S. Moore[1] as follows:

---

[1] Manuscript names of undescribed species.

> The concretions take several different forms. Some of those from a well 1,350 feet deep, at Saratoga, are pisolitic, as they consist of concentric spheres and are from 3 to 5 mm. in diameter. They are of a dirty-white color. Other samples show irregular structures and the material is porous, somewhat like very fine-textured pumice in appearance, and this type was found in wells in both areas. In some cases the structures take the form of rings and resemble travertine, which has been deposited around stems or roots of trees.
>
> The most interesting type, however, came from a well at Saratoga at a depth of 1,130 feet. These are large oölites ranging in size from 1.25 to 3 mm. in diameter and varying in shape from nearly perfect concentric spheres to ovoids. In thin-section they usually show a great number of extremely fine lines marking the outlines of the spheres. The mineral is cryptocrystalline to amorphous and somewhat opalescent in appearance.
>
> In the center of the oölite there is generally an area of irregular shape occupied by material which is more porous than that surrounding it and it is not concentrically arranged. It consists of an earthy mass, sometimes slightly stained with iron oxide, with extremely small crystals of what seems to be barite arranged along open spaces and mixed with the earthy material. It is possible that some of these crystals are barium-orthoclase, as the optical properties correspond to those of that mineral. The interference colors are bluish gray and the extinction angle is zero or very small. A little calcite was found in two thin-sections and a little quartz in another, while it is believed that a small amount of clay is also present. In four thin-sections examined and in the large number of concretions crushed for purposes of analysis no definite body, such as a sand grain or similar structure, was found serving as a nucleus. Outside of the earthy, central mass the material is concentrically arranged and the spheres marked by very fine lines. It appears that the concretions began to form by deposition of barite in both a crystalline and earthy condition, with small amounts of other minerals, and that this later continued to precipitate more rapidly in a purer condition, either as a replacement of some other mineral or in open spaces in the sand. No evidence of replacement is found unless it be the traces of calcite existing in some oölites, as the concretions are loose and not embedded in a solid rock.
>
> In color the oölites are white to bluish gray, and they are very smooth on the outer surface. From their appearance they were at first thought to be chert concretions, but an examination showed a specific gravity of 4.25 and a flame coloration for barium, strontium, and a trace of potassium.
>
> The Saratoga barite somewhat resembles that from Montana in color and form, but it is distinctly oölitic or pisolitic, and it is partly cryptocrystalline to amorphous.

---

[1] E. S. Moore, "Oolitic and Pisolitic Barite from the Saratoga Oil Field, Texas," *Geol. Soc. Amer. Bull.*, Vol. 25, pp. 77–79.

As stated above, the flame test indicated barium, strontium, and a trace of potassium. A chemical analysis made by Mr. L. J. Youngs, of the Department of Geology and Mineralogy of the Pennsylvania State College, to whom I am indebted for these figures, shows the following percentages:

SiO_2	0.98	SO_3	35.104
Al_2O_3	0.41	H_2O	0.55
FE_2O_3	0.07	Vol. matter	
CaO	2.129	$BaSO_4$	88.54
SrO	2.067	$SrSO_4$	3.76
BaO	58.17	$CaSO_4$	5.17

In discussing this matter with Mr. E. G. Woodruff, he stated that at least some of these concretions undoubtedly formed in the wells after they were equipped, because they had been found reaching a quarter of an inch in diameter, in a well with a screen on the tubing, the mesh of which was altogether too small to admit a concretion of the size stated. . . . . When a nucleus is present it consists of earthy material made up mostly of clay and barite and this mass is often stained with iron oxide which gives the center of the concretion a brownish tint.

This additional information is interesting from the standpoint of its bearing on the origin of concretions. It would be practically impossible for bacteria or other low types of life, which are believed to play an important part in the origin of oölites, to exist in a liquid with such strong antiseptic qualities as those of warm petroleum containing considerable sulphuric acid. It would seem to demonstrate that living organisms are not essential to the development of oölites and that these may form where precipitation is taking place in an agitated solution, in the absence of life.

Oil and gas.—The oil and gas at Saratoga is very irregular in its occurrence, and correlation from well to well is extremely difficult. On account of local cementation of sand layers into hard, limy sandstones logged as "rock," great difficulty is experienced if one tries to correlate on rock strata. Logs of wells drilled very close together vary considerably as is evidenced by wells Nos. 295 and 288 of the Rio Bravo Oil Company. These wells are only 30 feet apart and yet their logs are entirely dissimilar. From a study of logs one could easily jump to the geologist's stock conclusion that the dissimilarity was all due to the rotary system of drilling and the drillers; but the writer's close observation of the field over a period of about eleven years leads to the conclusion that the drillers' logs are reliable. There is so much difference in the way that sand, shale, gumbo, and rock drill that a driller would have to be most ignorant and careless to make large errors in his log. All drillers for the Rio Bravo Oil Company log changes in formation accurately as soon as they have gone from one formation into another. The conclusion reached is that there is a marked lensing or change in formation laterally at Saratoga and the oil is found in certain zones, and that accumulation is governed in some cases by this phenomenon. This condition and the occurrence of water, oil, and gas at Saratoga is very well described by Fenneman[1] as follows:

> While any one bed, whatever its composition, may pass laterally into a bed of any other composition, and the drill is therefore liable to encounter almost any material at almost any depth, there are certain horizons which are characterized by a large predominance of one kind of material. As an illustration of this, there is in almost all of the wells in the southwestern part of the field sand or gravel, or both, at a depth approximating 500 feet. That this occurrence represents merely a horizon abounding in local sands and gravels and not one continuous stratum is plain from the diversity in thickness, number of beds, and depth reported. Thicknesses vary from a few feet to more than a hundred. In one well there may be but a single bed of great thickness; in another near by the sands or gravels at approximately the same horizon may appear in half a dozen beds separated by intervening clays. The minor diversities of depth would require that any scheme of correlation should hypothesize sharp folding of these unconsolidated sediments. In the same part of the field [the southwest], depths between 800 and 900 feet generally show sands to which the description given above would apply. In at least a small part of this quarter of the field a thick sand has been found in all the deep wells between 1,400 and 1,500 feet. It is possible that this sand is a single and well-defined bed. In the northern part of the field sands have been found quite generally at depths between 900 and 1,000 feet. Above this sandy horizon, for a thickness of from 200 to 400 feet, little sand is found, the sediment being almost entirely clay. The same is true of the 100 or 200 feet of sediments overlying the sandy zone found at a depth of 800 feet in the southwestern part of the field.
>
> While the sandy zones here described are not to be understood as continuous strata, but rather as large thicknesses within which limited beds of sand are very frequent, it may still be true that these small beds are so thickly crowded as to afford continuous passage for fluids [Fig. 5]. For example, it seems certain that in the southwestern part of the field the 500-foot horizon of sands and gravels is for all practical purposes an artesian stratum. It is, however, distinguished from an artesian stratum, strictly so-called, by the fact that its varying depths at different places do not indicate dips of the beds. This being the case, it is impossible to infer from even a large list of depths, however carefully correlated, what the depth of the sand might be at any other place, however near.

[1] *Op. cit.*, pp. 58–69.

Showings of oil are found at almost any depth and at irregular intervals. There is no considerable thickness of sediment which does not in some part of the field afford a showing of oil or gas. In the southwest quarter of the field oil in commercial quantities has generally been found in the sands at a depth of 800 or 900 feet. The deeper oil, which has been obtained from a small spot in this part of the field, is found in the thick bed of fine sand encountered at a somewhat uniform depth of about 1,400 feet. In the northern part of the field most of the oil has been found between 900 and 1,000 feet deep. In each case the almost complete absence of sands from the next higher clays has given to the latter the character and function of a cap rock.

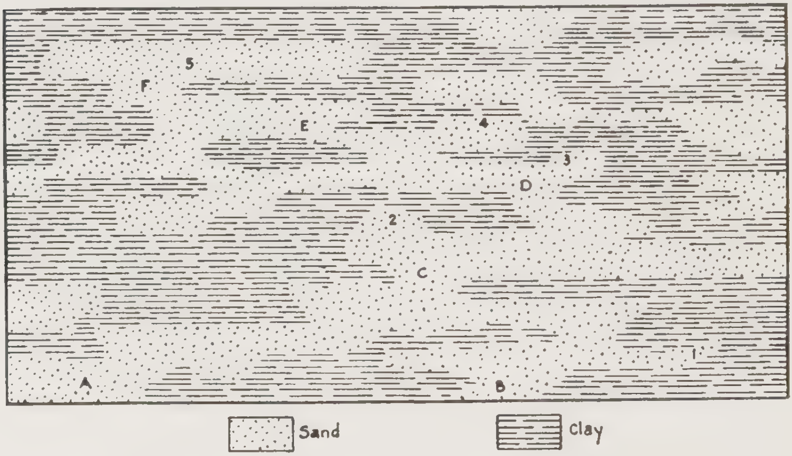


FIG. 5.—Illustration (after Fenneman) showing accumulation of oil in sandy zones in beds having little dip.

Ideal section of irregularly interbedded sands and clays. Oil may be borne up from *A* and *B* past *C, D, E,* and *F,* accumulating at 1, 2, 3, 4, and 5. The proportion of clay may be much larger than here represented, and the motion of the fluids may be more nearly horizontal.

The oil in this field is not generally accompanied by the large amount of gas found in the rock wells of Spindletop, Sour Lake and Batson. With the exception of a few wells, gushing has been of a milder type than that of the other fields named. However, while gas does not usually accompany the oil in large quantities, it is abundantly present in separate bodies. No field in Texas (Humble excepted) has furnished such spectacular blowouts as Saratoga. Generally the beds from which these violent eruptions have occurred are in the upper half of the well section; that is, above the clay zone which overlies the oil. In the northern part of the field large quantities of gas were found at about 500 feet. In the Rio Bravo No. 215 there were blowouts from depths of 200 and 600 feet. The same company's Well No. 211 probably furnished the most violent example. A pocket of gas was struck at approximately 500 feet, giving rise to a blowout so violent that the surrounding ground was affected by cracks to a distance of 250 feet. From these cracks there were eruptions of mud at distances of at least 200 feet from the mouth of the well. A crater was formed a few rods in diameter and more than 20 feet deep. The machinery and the wreck of the derrick were swallowed. The danger of such occurrences was for a time one of the chief difficulties in drilling in this field. At least one similar blowout, though less violent, occurred from the 1,400-foot sand, or at about that depth.

The ground waters of this field are fresh to a much greater depth than those of the other Hardin County fields. The strong flow usually met at a depth of about 500 feet in the southwestern part of the field is always reported as fresh. It appears that, by ill fortune or carelessness, this water was not properly cased off in certain wells. When the wells were drilled through the underlying clay, this water was given access to the sandy zone containing the oil and soon appeared in other wells, which had been pumping oil alone. The admixture of this water was the more unfortunate on account of the fact that fresh water is separated from the oil with greater difficulty than salt water.

Below the level of the clay zone which overlies the first important oil the water encountered is salt. The amount of salt water pumped previous to the drilling of the deep wells was small. The 1,400-foot sand, after yielding oil abundantly for a few weeks, began to produce large quantities of salt water.

All the production obtained at Saratoga has come from sands lying above the cap rock. This is in marked contrast to Spindletop, Sour Lake, and Humble where the early gushers and a large percentage of the early production was obtained from the porous limestone or dolomite designated as cap rock. In all cases where the cap rock has been tested at Saratoga it has yielded only hot black sulphur and salt water, in some cases carrying a very small showing of oil. The warmest water measured by the writer was from 1,600 feet depth and had a temperature of 115° F.

In comparison with other Gulf Coast fields the Saratoga oil is rather heavy. The specific gravity varies from 15° to 22° A.P.I., according to the depth at which it is found, the gravity at depth being about as follows:

600– 800 ft................	15°–16° A.P.I.
800–1,000 ft................	17°–18° A.P.I.
1,100–1,500 ft................	19°–22° A.P.I.
1,500–1,900 ft................	22°–26° A.P.I.

There are, however, certain rare, freak wells of shallow depth in the field which have yielded oil up to 26° A.P.I.

The Saratoga oil in common with all Gulf Coast crude is of neither a paraffin nor asphalt base, if these terms are allowable, but is of a neutral or napthene base. This crude runs extremely high in zero cold test lubricants as the following analyses show:

ANALYSIS OF PETROLEUM FROM SARATOGA, TEXAS

Physical characteristics:	
Color	Black
Odor	Strong H_2S
Specific gravity	18.4 A.P.I.
Flash	230° F.
Sulphur	0.835%
Commercial product (by Sinclair Oil and Gas Co.):	
Gas oil	28.0%
Lubricant stock	29.0%
Fuel	39.0%
Loss	4.0%
	100.00%
Commercial product (by Rio Bravo Oil Co.):	
Gas oil	40.4%
Finished lubricant	31.6%
Fuel	19.6%
Loss	8.4%
	100.00%

The average 18° A.P.I. Saratoga crude is conceded to be equal to any in the Gulf Coast in amount of lubricants recovered, but the high sulphur content causes some trouble in the refining.

PRODUCTION

Up to the end of 1923, about 884 wells had been drilled at Saratoga on 672 acres. From this drilling 22,861,841 barrels have been recovered, or 34,000 barrels per acre and 25,800 barrels per well. On the Rio Bravo Oil Company property 7,142,642 barrels have been recovered by drilling 184 wells on 272.7 acres, or 31,500 barrels per acre and 38,800 barrels per well. Mr. Charles Paggi[1] states that the Teel 1-acre tract located in the northern part of the Cotton survey has produced to date about 300,000 barrels of oil. This is not high recovery for the Gulf Coast country but it shows what can be expected from a field which has never had cap-rock gusher production or deep-flank gusher production.

---

[1] Private communication.

One of the saving graces of the Saratoga field has been that although one never knows when starting a well where he will find a good sand or how much initial production to expect, he can usually count on the expense of drilling being fairly low. Out of 184 wells drilled by the Rio Bravo Oil Company since 1903, the average cost per well has been $4,760. Wells 1,000 feet deep have been drilled completely equipped for pumping, including casing, strainer, rods, and tubing, at a cost as low as $1,600. The average cost for a completely equipped 1,400-foot well prior to 1914 was about $3,500. Of the 184 wells drilled by the Rio Bravo Oil Company, the average initial production was 110 barrels; the highest initial production, 3,700 barrels; and the lowest, 3 barrels. Of the 184 wells drilled by the Rio Bravo Oil Company, only 11 have been dry holes.

All drilling is done by the rotary system. When not cemented into sandstone the upper 500 feet or so of Columbia and Lafayette sands and gravels drill very easily, and it is not at all uncommon for a drilling crew to make 300–450 feet of hole in the first day's drilling. It is also not at all uncommon to drill and complete a well to the 800-foot sand in seven or eight days. When the upper sands are cemented and hard, the drilling is slower. It is of interest to note that some of the earliest coring with the rotary was done here in 1905. As rock bits had not been invented, it was common practice to use a plain slotted-end core barrel and adamantine. Cores 10 and 12 inches in diameter were removed. After coring, the rock drilling in the softer formations with fish-tail bit was resumed.

The present practice is to drill an 8-inch hole down to a tough gumbo stratum lying just above the zone in which oil is expected. Ordinary 6-inch line pipe is landed for casing and a formation shut-off made. The hole is usually bailed to test for shut-off, and these tests are usually satisfactory. No instances are known of any water strings ever having been cemented at Saratoga. After the testing for the shut-off, drilling is resumed with 5⅞-inch fishtail bits. The first sandy zone encountered is watched closely for oil content. Oil is usually found in what is logged as "sand and shale." If the first sands encountered seem to be water sands, drilling is continued until an oil sand is encountered. Usually 50 or 60 feet of the oil-bearing sand and shale is desired. As soon as enough of this formation has been encountered to make it fairly certain that some kind of a well will be obtained, the drilling is stopped and strainer is set. The strainer string is usually the 4- or 4½-inch size.

If a water sand is thought to be present above the oil sand to be tested and below the bottom of the 6-inch casing, a canvas "boot-leg" packer is run on the strainer string preferably to come opposite a layer of gumbo. The object of this boot-leg packer is to make a shut-off between the supposed water sand and the supposed oil sand. It is really remarkable how often this method of shutting off water is successful.

The strainer string contains the strainer to be set opposite the oil sand, the boot-leg packers, and on the bottom a back-pressure valve and a wash plug. Wash pipe, usually 2-inch size, is placed inside the strainer with a wash ring at the top. It is run into the hole and held about 2 feet off bottom. The hole is then washed with clear water to remove drill mud from the face of the oil sand, and after washing operations are finished the pipe is set down on bottom. The wash pipe is then fished out and the hole bailed. If the gas pressure is not strong a great deal of bailing may be necessary. Sometimes a well may be bailed for a week or so before it comes in. Wells good for 200 or 300 barrels will usually flow some as soon as bailed down.

The sands in the Gulf Coast fields are usually soft and fine grained. This necessitates setting of very fine strainer. The average strainer set has openings between the wire for admission of fluid of only .012 inches width. The three sizes of strainer most commonly used are as follows:

Layne & Bowler	McEvoy	Getty (Mesh)	Width of Opening in Inches
.012	12	50	.012
.010	10	60	.010
.009	9	70	.009

Of late years it has become common practice to run the 4-inch strainer string up into the 6-inch casing only 50 or 60 feet. In this case a canvas adapter packer is set between the 4-inch and 6-inch to make sure that water does not enter the well between them. The strainer-string containing this packer is run in on the drill stem with setting tool attached. After washing and setting the packer, the drill stem is pulled and the wash pipe comes out with it.

It sometimes happens that where 50 or 60 feet of strainer has been set the bailing will show nothing but salt water. In such cases it is customary to cement off the bottom of the setting 5 or 10 feet at a time to see if the water is bottom water. This is often a successful operation and many good wells have been made in this manner.

Frequently after completing a well as dry it is decided that there are sands behind the water string which should have been tested. This condition often arises after a well goes dry which has been pumping for ten or twelve years. If the well has but recently been completed, it is customary to drop a whip-stock in the hole and mill through the 6-inch pipe about 50 feet above the point where it is desired to test. A $5\frac{7}{8}$-inch hole is then made down to the sand and strainer set in the customary manner, using plenty of boot-leg packers. In an old well where the mud behind the pipe has had a chance to settle for several years, it is customary to perforate the water string opposite the sand. Remarkable results are frequently obtained in this manner. For instance, well No. 212 B.B.B. & C., of the Rio Bravo Oil Company, was drilled to a depth of 1,057 feet in May, 1904, and had an initial production of 119 barrels. In 1914 the production had declined to 1 barrel per day and it was decided to perforate the 6-inch casing opposite a sand logged from 850 to 865 feet. This was done and the well started off with 60 barrels per day initial production of 17° A.P.I. gravity oil and no water.

In carrying on repair work the 4-inch strainer string is often perforated in places where no strainer was set. This sometimes gives good results. In fact, when a well gets down to the point where abandonment is necessary, it is usually perforated opposite all logged sands below 600 feet before it is given up as hopeless. In addition, there are some instances where the perforating or ripping of old strainer has been extremely successful. After perforating operations an attempt is first made to pump the well without setting strainer. If the sand bothers too much, $2\frac{1}{2}$- or 3-inch strainer must be set inside the old 4-inch.

It is common practice on the Gulf Coast to deepen a well by drilling out the wash plug and back-pressure valve set on the 4-inch strainer string. Two-inch drill stem is used in this work. The well is deepened until new sands are picked up and a 2½-inch strainer is set through the 4-inch opposite the lower sands. Sufficient packers are used in this setting to pack off fluid which might enter the hole from the 4-inch strainer.

While drilling costs at Saratoga are relatively low, the pumping costs are high, due to the large amount of sand which comes into the wells sooner or later. This necessitates frequent pulling of rods, frequent replacement of pumping equipment, and the using of special material. The lifting cost is also high because of the small amount of oil produced per well and the large amount of water which the wells make and which must be handled by the pumping equipment. The average lifting costs in cents per barrel for the Rio Bravo Oil Company since 1905 have been as follows:[1]

	Cents per Barrel
1905	4.38
1906	6.21
1907	8.91
1908	11.07
1909	15.34
1910	16.03
1911	14.43
1912	14.70
1913	22.87
1914	20.97
1915	22.39
1916	23.13
1917	18.13
1918	41.01
1919	45.68
1920	77.06
1921	64.81

The wells now producing in the field average less than six barrels per well. All wells in the field make water and emulsion in varying amounts. The average emulsion reaching the treating plants averages 50–60 per cent water, and in addition to this a large amount of water has probably been bled off at the flow tanks and settling tanks before the oil is pumped to the treating plants.

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[1] This item includes the cost of labor and material on pumping wells, cost of superintendence, and cost of collecting oil.

The Saratoga emulsion is very hard to treat, and considerable trouble is experienced in removing the water. Some of the production is treated by electric dehydration but the greater percentage is treated by steam heat to remove the water.

ACKNOWLEDGMENTS

This paper is based on a close study of the Saratoga field during the past eleven years. The author has drawn also on such published data as could be used.

THE BATSON OIL FIELD, HARDIN COUNTY, TEXAS

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ABSTRACT

The Batson oil field, which has produced 32,000,000 barrels of oil, is underlaid by an elliptical anhydrite-capped salt plug, 2 miles long and 1½ miles wide. The formations encountered are Pleistocene to Oligocene. Most of the production comes from the cap rock and Oligocene formations. The field is now (1925) producing 1,400 barrels per day from 400 wells. Production curves, contours on the cap rock and cross-sections are shown.

INTRODUCTION

Location.—The Batson oil field is located on the west fork of Pine Bayou, 1 mile north of the village of Batson in Hardin County, Texas, 6 miles west of Saratoga and 9 miles north of Hull. The nearest railroads are the Gulf Coast & Santa Fe through Saratoga and the Beaumont, Sour Lake & Western through Hull.

History.—After the production from the two Gulf Coast oil fields, Spindletop and Sour Lake, began to decline, the Paraffine Oil Company was organized by S. W. Pipkin, W. L. Douglas, and other business men of Beaumont who had, up to this time, no experience in the oil business. Previous to this, W. L. Douglas, who had observed gas in some water holes and shallow wells in this vicinity, sent some samples of spongy earth to a Beaumont chemist who reported that they contained paraffin. Although the idea that this material was an indication of oil was ridiculed for some time, paraffin earth, which was first collected at Batson, is now considered one of the best indications of oil in the Gulf Coast.

On October 31, 1903, nine days after their drilling rig was unloaded at Liberty, the Paraffine Oil Company completed a well at a depth of 790 feet producing 600 barrels of oil per day. Six weeks later their No. 2 was flowing over 4,000 barrels per day from a depth of 1,000 feet. Their No. 3 well went into cap rock and the initial production was 10,000 barrels per day.

Since the location of the discovery well proved to be near the center of the dome, a rapid drilling campaign took place and the peak production, 150,000 barrels per day, was reached March 4, 1904, after which, due to salt water, the decline was very rapid (Fig. 1).

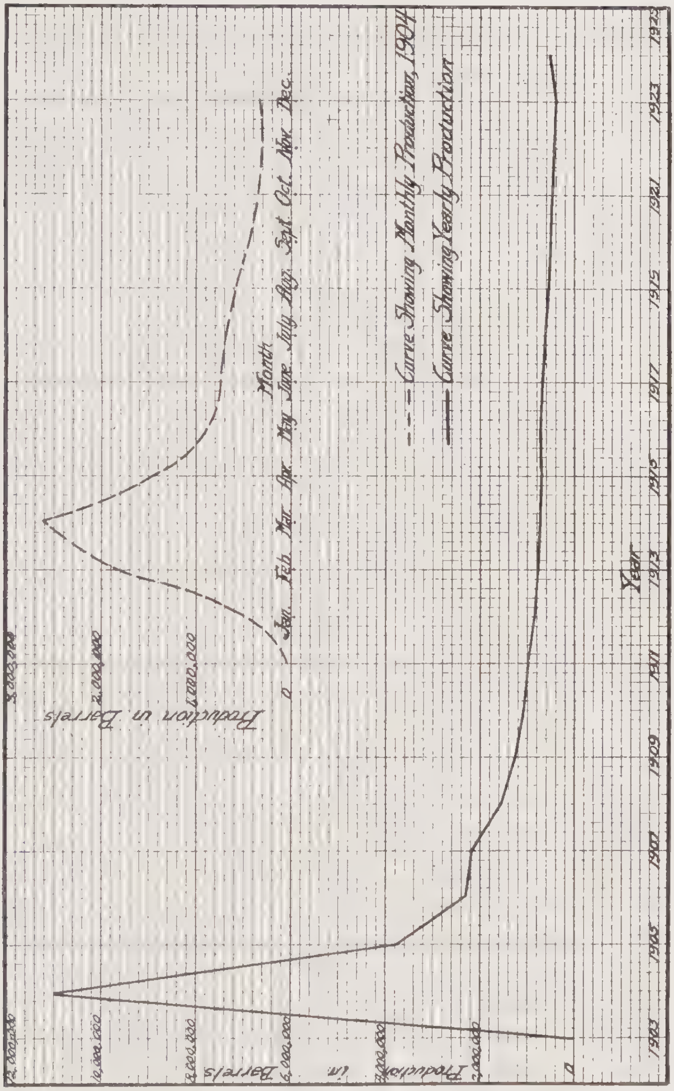

FIG. 1

PHYSIOGRAPHY

The surface elevation of the Batson field is 60 feet above sea-level and not more than 10 feet above the surrounding country. Because of dense forest this small relief could not be observed when the field was discovered.

SALT CORE

The Batson field is underlaid by an anhydrite-capped salt core which is elliptical in horizontal plane with the major axis running in a general northwest-southeast direction. The top of the dome is greatly undulating and covers an area of 400 acres. The highest point on the cap rock is 1,081 feet below the surface. At the 4,000-foot contour the dome is 2 miles long and 1½ miles wide (Plate 8).

Since most of the wells drilled at Batson lost returns in or near the cap rock, only one well was carried into the salt. The Gulf Production Company Douglas No. 3 hit cap rock at a depth of 1,162 feet and salt from 2,050 feet to 2,170 feet. The Gulf Production Company Wing No. 138 hit cap rock at 1,412 feet and had hard rock with thin layers of gypsum to 1,812 feet. Both of these wells were abandoned.

The Kirby Petroleum Company obtained cores of white granular massive anhydrite from three wells on the west side of the dome. None of the logs obtainable showed any sulphur.

Drillers who had completed wells on the west side of the field stated that there were a false cap and a break of soft material above the real cap rock. Cores from the Kirby No. 1 Milhome showed this false cap to be 6 feet of highly cemented sandstone and the soft material to be 4 feet of volcanic ash.

SEDIMENTS

The surface material at Batson is a mixture of sand and clay, probably of Pleistocene age. Wells off the dome show 1,000 feet of Lafayette and under this from 1,200 to 1,800 feet of Fleming, followed by 200 feet to 800 feet of Oligocene. On top of the dome there is a thinning and compression of beds (Fig. 2).

A core from the Cavit-King No. 1 shows Oligocene at 1,180 feet. The Cavit-King No. 2 shows volcanic glass suggestive of the Oligocene at 1,060 feet. The lithology of a sample taken from one of the

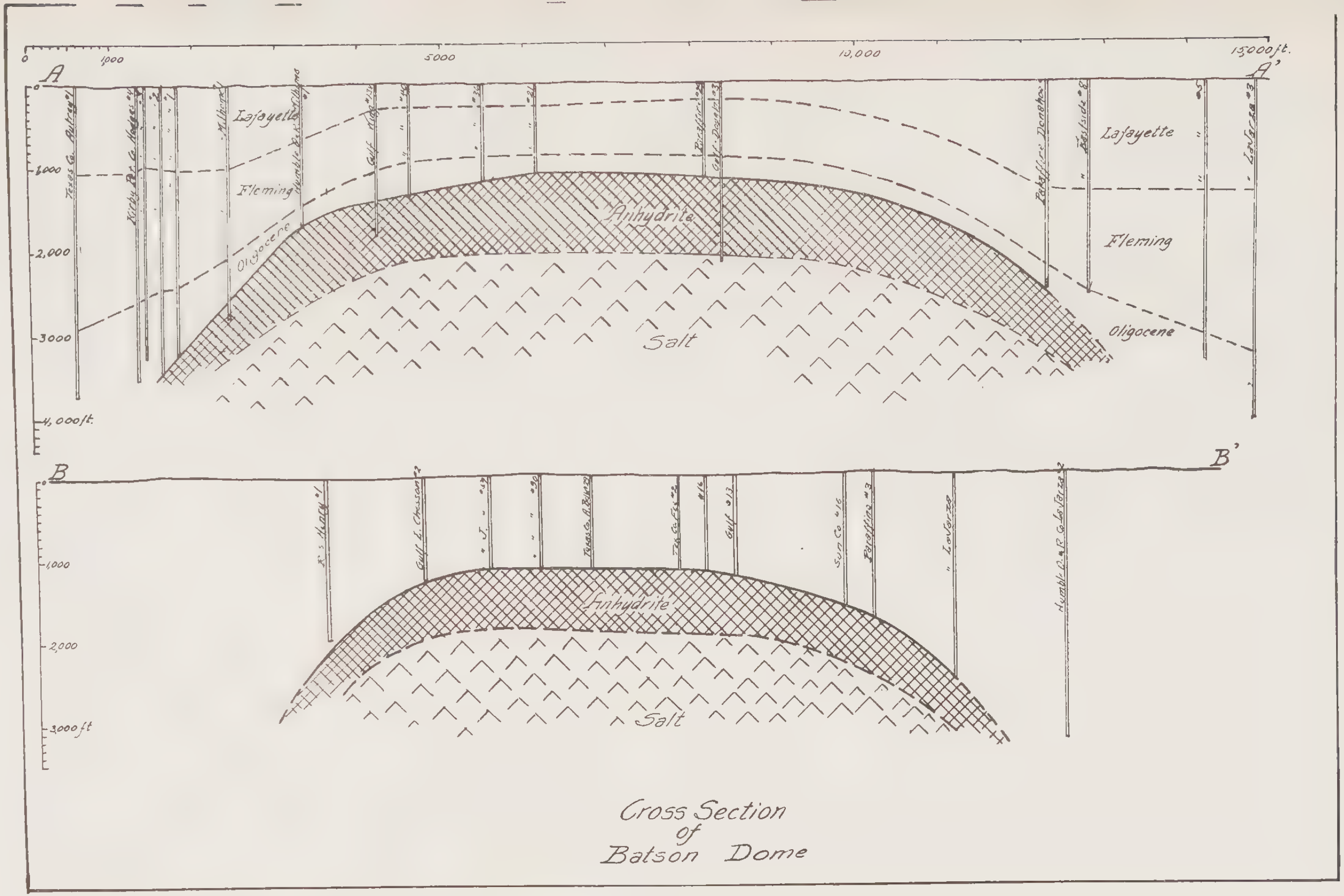
0
1000
5000
10,000
15,000 ft.
A
A'
0
1000
2,000
3000
4,000 ft.
Texas Co. Autrey #1
Kirby Pet. Co. Hodges #4
Milheim
Humble Pet. Co. Williams
Gulf King #13
Paraffine
Gulf Donahoe #3
Paraffine Donahoe
Eastside #8
Lafayette
Fleming
Oligocene
Anhydrite
Salt
B
B'
0
1,000
2,000
3000 ft
Gulf L. Chesson #2
Texas Co. A. Bivens
Gulf #13
Sun Co. #16
Paraffine #3
Lovarza
Humble O. & R. Co. Lovarza #2
Anhydrite
Salt
Cross Section of Batson Dome

FIG. 2

Paraffine wells on the top of the domes compares with that frequently found in the upper non-fossiliferous Oligocene (cores examined by A. C. Ellisor.) The Oligocene in the Texas-Autrey No. 1 on the west side of the dome is approximately 400 feet higher than the same formation in the Paraffine-Humble Lejarza No. 3 on the east side.

The Eocene has never been observed in any of the Batson wells, but the following cores containing a foraminiferal fauna indicative of the Oligocene have been found in wells off the dome:

Texas Company-Autrey No. 1, samples examined by H. T. Kniker,

Depth 3,063 feet
Balanus sp.
Discorbis bertheloti
Globigerina sp.
Depth 3,156 feet
Amphistegina lessonii
Pulvinulina texana
Depth 3,704 feet
Haplophragmium sp.
Polystomella striatopunctata

Paraffine-Humble Lejarza No. 3, samples examined by A. C. Ellisor,

Depth 3,747 feet
Heterostegina antillea
Polystomella texana
Pulvinulina texana
Cristellaria sp.

It is interesting to note that in the Texas-Autrey No. 1, 1,000 feet off the west side of the dome, a sand core from a depth of 3,063 feet had a dip of 47 degrees, a sandstone core from 3,170 feet showed a dip of 38 degrees, and a shale core from 3,729 feet had a dip of 44 degrees.

PRODUCTION

The 1,150 wells drilled in the Batson field have produced over 32,000,000 barrels of oil from 560 acres of land ranking eighth among the Gulf Coast fields in total production, and it is now (1925) producing 1,400 barrels per day ranking tenth in present daily production. Part of this oil comes from the cap rock, and part of it is produced from sands which are encountered at various depths from 189 feet to 3,500 feet. One company, now producing oil in this field, is pumping 44 wells averaging 10 barrels per day per well and their lifting charge is 40 cents per barrel.

Batson has produced a great variety of oils. The Sun Company had a shallow well yielding 14.6° Bé. oil. The Kirby Petroleum Company brought in a 5,000-barrel well on the Hodges lease with 40° Bé. gravity oil at 3,230 feet, but it produced only a few days.

Since this rapid decline is the history of nearly all light oil wells in the Gulf Coast, a method was desired whereby the gravity of the oil could be determined by analysis of the oil from the core, thus eliminating the testing of sands which contained light oil. Dr. L. Porter, chemist for The Texas Company, had previously suggested the miscibility of water and alcohol. Many experiments in the Kirby Petroleum Company laboratory resulted in the following very successful method: The oil is leached from a sand core with ether and a drop of the oil obtained is added to a quantity of alcohol in a hydrometer jar. The oil, being heavier than alcohol, sinks. By the slow addition of water an alcohol-water solution can be obtained which has the same gravity as the oil, thus causing the drop of oil to migrate through the solution. The gravity of the solution is then obtained by the use of a hydrometer. In two offset wells, the application of this method enabled the operators to set screen in sands which produced 24° Bé. and 20° Bé. gravity oil.

Many wells on the west side of the dome encountered an enormous gas pressure at depths of 1,800 feet, 2,800 feet, and 3,200 feet, but the pressure never held up for more than a few days. The high pressure was probably due to the fact that the formations there are sealed by compression and faulting. For the same reason none of the oil wells drilled on the Hodges lease have held up although all four of these wells came in with an initial production of more than 1,000 barrels per day per well.

ACKNOWLEDGMENTS

Samples of cap rock were furnished by W. G. Christian, of Houston, and cores of the shallow sands were furnished by W. H. Cavit, of Batson. Logs of wells were secured from the Paraffine Oil Company, Humble Oil & Refining Company, Gulf Production Company, and The Texas Company. The paleontological analyses of cores by A. C. Ellisor were especially helpful.

THE BARBERS HILL OIL FIELD, CHAMBERS COUNTY, TEXAS

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ABSTRACT

Barbers Hill is a moundlike elevation in the extreme northwestern portion of Chambers County, Texas, 26 miles northeast of Houston. It is oval in shape, covers an area of 1,718 acres, and rises 45 feet above the surrounding prairie. This elevation is the result of an intrusive salt plug which has raised the surface above its normal position.

The salt plug is composed of almost pure rock salt and is capped by deposits of gypsum anhydrite and limestone. Formations surrounding the salt plug are inclined at steep angles dipping away from the salt plug.

Numerous indications of geologic disturbance are present on and about the dome. The most prominent of these are mineralized water-and-gas seepage in shallow water wells, paraffin dirt, and gas seepage on the surface.

Prior to 1924, 120 wells were drilled, of which 26 produced oil and 91 were failures. The total production for this period is 784,520 barrels, all of which was obtained from an area of 100 acres on the southwestern side of the dome. The average production of producing wells has been 30,174 barrels, and the average depth 2,251 feet. The oil has an asphaltic base with gravities ranging from 17° to 39°.7 Baumé; the oil produced from cap rock averages about 20° Baumé. Production around the periphery of the dome is obtained from sands and limestones of the Fleming formation.

INTRODUCTION

Barbers Hill is a moundlike elevation in the extreme northwestern portion of Chambers County, Texas. It is 26 miles northeast of Houston, 11 miles north of Goose Creek, and 21 miles southeast of the Humble oil field. The village of Mont Belview is situated on top of the mound. The most convenient method of approach is by automobile from Houston. It is also accessible via the Dayton and Goose Creek Railroad, which connects with the main line of the Southern Pacific at Dayton.

HISTORY OF DEVELOPMENT

In 1889, Mr. E. W. Barber encountered inflammable gas while digging a 65-foot water well near his home. The well is located near the top of the mound and produced small quantities of gas for many years.

Following the discovery of oil at Spindletop in January, 1901, Barbers Hill was one of the first prospects to receive the attention of early operators.

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Its prominent elevation, with inflammable gas and sulphurated water in shallow wells near the top, strongly suggested the presence of an underlying salt dome.

During the month of February, 1902, Dr. George Collier recorded the first oil-and-gas leases taken at Barbers Hill; these leases covered the Old River, Lawrence, and Barber tracts. A portion of these holdings were transferred to Patillo Higgins under a drilling agreement, and four months later the first well was started on the Old River tract, well up on the northwestern slope of the hill. After reaching a depth of 934 feet, the well was junked in hard cap rock. A showing of heavy oil is reported in sand at 800 feet immediately above the cap rock. A total of five wells were drilled by Mr. Higgins, all of which encountered cap rock showing a little oil but failed to obtain sufficient quantities to make commercial production. In 1903, Mr. J. M. Guffey entered the field jointly with the Higgins Oil and Fuel Company and drilled five wells. The first two locations were on the Mary Ellen property (now DeWitt Barber), on the southern slope of the hill. A small amount of heavy, viscous oil was obtained at 805 feet from sands immediately above the cap rock.

Fourteen wells were drilled during the next four years without obtaining production. All of these wells were shallow, the majority being located on top of the dome. Operators became discouraged, owing to the low price of crude oil from 1906 to 1916, and very little activity was manifest at Barbers Hill. However, the success attained by deeper drilling along the periphery of other domes finally led Mr. Guffey to make a location on the Fitzgerald tract at the base of the northern slope of the hill. A depth of 2,520 feet was reached after passing through a series of unconsolidated sands, clays, and gravel containing no oil. In 1916 the Gulf Production Company, successors to the Guffey interests, jointly with the Humble Oil & Refining Company, drilled four wells, all of which are located on the Chambers County Agricultural Association's land near the southern slope of the hill. The fourth well obtained the first production at Barbers Hill, estimated at 40 barrels per day, from a sandy formation at 1,571 feet. The oil is reported as dark brown in color, heavy and viscous. The well was abandoned when salt water appeared after the production of a small quantity of oil. In 1918, Mr. Sam Hindman organized the United Petroleum Company and completed Fisher No. 1, on September 14, 1918. The initial production was 70 barrels per day of oil of 23° Baumé gravity, and the well continued to produce for a period of fifteen months. This was the first successful completion in sixteen years of drilling.

The success of this well, together with an increase in the price of crude oil, was responsible for many new locations. Several wells were completed later in the year, and by January 1, 1919, production had increased to 600 barrels per day. The decline was very rapid, however, and by April 15 there was insufficient oil to supply fuel for drilling operations. However, the completion of a 650-barrel well by Benkenstein on the Collier tract, together with other producers by the Texas Company and United Petroleum Company, increased the daily average production to 1,000 barrels during the months of August and November, 1919. In April, 1920, the United Petroleum Company completed Richardson No. 4 as a 700-barrel well at 1,960 feet. The oil had a gravity of 21° Baumé and was the best producer so far obtained.

The year 1921 was a period of relative inactivity, with the exception of the United Petroleum Company's No. 1 E. E. Barrow, which was completed during the latter part of December at a depth of 3,560 feet for 800–1,500 barrels per day of oil of 35° Baumé gravity. This was the first well to secure oil from edge sands around the dome and was by far the best producer of the field.

An active drilling campaign followed in an effort to develop the newly discovered productive deep sands, the United Petroleum Company, Humble Oil and Refining Company, and Mills Bennett being particularly active in this work. By October, 1922, the monthly production had increased to 53,800 barrels This increase is largely due to the completion of Japhet No. 1 in October, 1922, by Mr. Bennett. It is the best well so far obtained at Barbers Hill and has remained a consistent producer to the present time. Initial production was 1,800 barrels per day, with a temperature of 78° F. The oil is of 34°5 Baumé gravity and is similar to that obtained from the United Petroleum Company's No. 1 E. E. Barrow.

In 1923 the Texas Company drilled three wells on the northeastern portion of the dome without obtaining production. Sheffield No. 1 and No. 2 were abandoned in broken cap rock, showing a little heavy oil. No. 1 Scott was abandoned at 4,635 feet without obtaining a showing of importance. Outside of the Texas Company's operations, very little new work was attempted, and by January 1, 1924, there were but 5 producing wells, having a combined daily average of 550 barrels. At the present time (August, 1924), there are 3 producing wells in the field, having a combined daily production of 150 barrels per day.

A total of 120 wells, including 10 wells which were primarily sulphur tests, have been drilled at Barbers Hill. Of these 26, or 21.7 per cent, were productive, and 94 non-productive. A total of 784,520 barrels of oil has been produced throughout a period of six years. The average production per well is 30,174 barrels, and the average depth is 2,251 feet. It is evident that the revenue from oil produced is little more than sufficient to pay for the drilling and operating costs. All of this oil has been obtained from an area of 100 acres on the southwestern portion of the dome and amounts to an average production of 7,845 barrels per acre.

PHYSIOGRAPHY

Barbers Hill lies within the Gulf Coastal plain, 33 miles inland from the Gulf of Mexico. It is surrounded by comparatively flat country, sloping gently toward the gulf at an average rate of about 1 foot per mile. The topographic expression of the salt dome is a hill somewhat oval in shape and covering an area of 1,718 acres (Fig. 1).

TABLE I

Development at Barbers Hill

Operator	Tract	Well No.	Date	In. Prod.	Depth in Feet	Remarks
Patillo Higgins	Old River	1	1902	Dry	934	Junked—cap rock, 800–934 feet
Patillo Higgins	Winfree, M. C.	1	1902	Dry	560	Aban. in cap rock
Patillo Higgins	Barber, E. W.	1	1903	Dry	1,176	Aban. in cap rock
Patillo Higgins	Williams, A.	1	1903	Dry	465	Aban. in salt
Patillo Higgins	Higgins, A.	1	1904	Dry	1,052	Aban. in cap rock
G. M. Guffey	Ellen, Mary	1	1904	Dry	980	Aban. in cap rock
G. M. Guffey	Ellen, Mary	2	1904	Dry	805	Cap rock, 800–805 feet
G. M. Guffey	C. C. Agric. Ass'n	1	1904	Dry	1,805	Aban. in gumbo
Sun Co.	Williams, A.	1	1904	Dry	1,802	Aban. in sand and salt
J. M. Guffey	Fisher, E.	1	1905	Dry	974	Aban. in cap rock
J. M. Guffey	Wilburn Z. T.	1	1905	Dry	1,030	Aban. in rock
J. M. Guffey	Smith, J. H.	1	1905	Dry	1,457	Salt, 1,388–1,457 feet
Higgins Oil & Fuel Co.	Higgins (Fee)	1	1905	Dry	1,104	Aban. in cap rock
Higgins Oil & Fuel Co.	C. C. Agric. Ass'n	1	1905	Dry	1,490	Aban. in salt
J. M. Guffey	Fisher, E.	2	1906	Dry	1,200	Aban. in cap rock
J. M. Guffey	Wilburn, B. F.	1	1907	Dry	1,100	Aban. in gypsum
Jos. Reviere & Co.	Hamilton, J.	1	1908	Dry	1,206	Cap rock and gypsum, 863–1,206 feet
Home Oil Co.	C. C. Agric. Ass'n	1	1910	Dry	1,250	
Home Oil Co.	Fisher, A. M.	1	1910	Dry	2,100	Tested salt water
J. M. Guffey	Fitzgerald	1	1911	Dry	2,520	Aban. in gumbo
Community Oil Co.	Monon Trust Co.	1	1912	Dry	1,930	Strong sulphur water
Gulf Humble	C. C. Agric. Ass'n	1	1916	Dry	2,283	Show of oil at 2,200 feet
Gulf Humble	C. C. Agric. Ass'n	2	1916	Dry	3,523	No cap rock
Gulf Humble	C. C. Agric. Ass'n	3	1916	Dry	1,200	
Gulf Humble	C. C. Agric. Ass'n	4	1916	40	1,571	Small production
Prairie Oil Co.	Wilburn	1	1916	Dry	2,385	Aban. in hard rock
Anahuac Oil Co.	Hamilton, J.	1	1917	Dry	410	
Hindman *et al.*	C. C. Agric. Ass'n	1	1917	Dry	1,380	Aban. in rock and gypsum
Benkenstein–W. P. Co.	Richardson	1	1918	65	1,600	21 gravity oil
United Petroleum Co.	Fisher, E.	1	1918	70	2,142	23 gravity oil
United Petroleum Co.	Fisher, E.	2	1918	300	1,065	18 gravity oil
R. L. Autry	Richardson	1	1919	200	1,491	19 gravity oil
Benkenstein Synd.	C. C. Agric. Ass'n	1	1919	270	1,860	18 gravity oil
Benkenstein Synd.	C. C. Agric. Ass'n	2	1919	Dry	1,870	Junked
Benkenstein Synd.	Collier	1	1919	650	1,847	18 gravity oil
Benkenstein Synd.	Old River	1	1919	Dry	1,680	Tested salt water
Benkenstein Synd.	Old River	2	1919	Dry	2,100	Tested salt water
Kavanaugh Pet. Co.	C. C. Agric. Ass'n	1	1919	Dry	2,165	No cap rock
Kavanaugh Pet. Co.	Fisher, E.	1	1919	Dry	1,340	Aban. in gypsum
Kavanaugh Pet. Co.	Fisher, E.	2	1919	Dry	1,960	Tested salt water
Hugh McCollum	Wilburn, B. F.	1	1919	Dry	1,300	Aban. in gypsum
Texas Co.	Fisher, Ben	1	1919	Dry	1,908	Tested salt water
Texas Co.	Fisher, Ben	1-A	1919	Dry	1,385	Aban. in gypsum
Texas Co.	Fisher, Ben	2	1919	200	1,918	21 gravity oil
Texas Co.	Fisher, Ben	3	1919	Dry	1,905	Tested salt water
United Pet. Co.	Fisher, E.	3	1919	Dry	1,910	Aban. in salt
United Pet. Co.	Richardson	2	1919	50	1,980	21 gravity oil
United Pet. Co.	Richardson	3	1919	Dry	2,385	Aban. in gypsum
DeWitt Barber	Ellen, M. (Gulf)	1	1920	Dry	1,032	Aban. in cap rock
DeWitt Barber	Ellen, M. (Gulf)	2	1920	50	820	17 gravity oil
DeWitt Barber	Ellen, M. (Gulf)	3	1920	20	810	17 gravity oil
DeWitt Barber	Ellen, M. (Gulf)	4	1920	25	845	Flooded by salt water
DeWitt Barber	Ellen, M. (Gulf)	5	1920	15	815	17 gravity oil
Gambler Oil Co.	Barber, O.	1	1920	Dry	1,200	
Gulf Coast–Crown	Barber, E. W.	1	1920	Dry	3,721	Aban. in gumbo
Keeble (Trustee)	Fisher, Ben	1	1920	Dry	350	Aban. in cap rock
Hugh McCollum	Wilburn	2	1920	Dry	1,600	No data
Old River Oil Co.	Richardson	1	1920	Dry	1,800	Little heavy oil
Old River Oil Co.	Richardson	2	1920	400	2,230	27 gravity oil
Spurrier Dev. Co.	Barber, O.	1	1920	Dry	1,231	Aban. in rock
Spurrier Dev. Co.	Wilburn, B. F.	1	1920	Dry	883	Aban. in gypsum
Spurrier Dev. Co.	Wilburn, B. F.	2	1920	Dry		
Texas Co.	Barrow E. E.	1	1920	Dry	3,324	Junked—blowout at 3,200 feet
Texas Co.	Barrow, E. E.	1-A	1920	Dry	3,460	
Texas Co.	Barrow, F.	1	1920	Dry	2,782	Junked
Texas Co.	Barrow, F.	2	1920	Dry	678	Junked
Texas Co.	Fisher,. Ben	3-A	1920	Dry	1,332	

TABLE I—*Continued*

Operator	Tract	Well No.	Date	In. Prod.	Depth in Feet	Remarks
Tex. Co	Old River	1	1920	Dry	3,941	Aban. in gumbo
United Pet. Co	Fisher (10 acres)	1	1920	Dry	2,653	Tested salt water
United Pet. Co	Richardson	4	1920	700	1,960	21 gravity oil
United Pet. Co	Richardson	5	1920	Dry	1,750	Aban. in salt
Gulf Coast—crown	Fisher, E.	1	1921	Dry	2,500	Salt, 1813–2,500 feet
Gulf Coast—crown	Fisher, E.	2	1921	Dry	2,265	Junked in hard rock
United Pet. Co	Barrow, E. E.	1	1921	800	3,560	34 gravity oil
United Pet. Co	Richardson	6	1921	Dry	2,070	Aban. in cap rock
Mills Bennett	C. C. Agric. Ass'n	1	1922	Dry	4,147	Tested salt water
Mills Bennett	C. C. Agric. Ass'n	2	1922	Dry	2,800	Aban. in salt
Mills Bennett	Japet	1	1922	1,800	3,236	34 gravity oil; tem., 78° F.
Mills Bennett	Japet	2	1922	1,700	3,760	
Mills Bennett	Japet	3	1922	800	3,503	27 gravity oil; tem., 80° F.
Dunnman Oil Co	Fisher, Z.	1	1922	Dry	2,625	Aban. in salt
Hindman *et al*	Japet	1	1922	Dry	2,858	Junked
Kirby Petroleum Co	Richardson	1-A	1922	Dry	2,405	
Kirby Petroleum Co	Richardson	1-B	1922	Dry	2,645	Junked
Kirby Petroleum Co	Winfree	1	1922	Dry	4,074	Aban. in sandy shale
Texas Co.–W. P. Co	Barrow, F.	1	1922	Dry	4,000	Tested salt water
United Pet. Co	Richardson	7	1922	Dry	3,030	Aban. in cap rock
United Pet. Co	Richardson	8	1922	400	2,238	
Mills Bennett	Barrow, E. E.	1	1923	Dry	3,488	Tested salt water
Mills Bennett	Barrow, E. E.	2	1923	1,000	3,817	39.7 gravity oil
Mills Bennett	Barrow, E. E.	3	1923	Dry	3,460	Tested salt water
Mills Bennett	Japet	4	1923	Dry	2,988	Tested salt water
Mills Bennett	Japet	5	1923	2,000	2,695	31 gravity oil
Coastal Oil Fields, Inc.	Barrow, F.	1	1923	Dry	60	
Coastal Oil Fields, Inc.	C. C. Agric. Ass'n	1	1923	Dry	1,700	
Coastal Oil Fields, Inc.	Fisher (fee)	1	1923	Dry	2,220	
Coastal Oil Fields, Inc.	Fisher, E.	1	1923	Dry	2,715	
Coastal Oil Fields, Inc.	Richardson	1	1923	300	2,225	29 gravity oil
Coastal Oil Fields, Inc.	Richardson	2	1923	Dry	2,385	Tested salt water
Hindman *et al*	Collier	1	1923	Dry	1,398	Aban. in anhydrite
Hindman *et al*	Collier	2	1923	Dry	951	Aban. in cap rock
Hindman *et al*	Fisher, E. H.	1	1923	Dry	1,302	Aban. in cap rock
Hindman *et al*	Shearer	1	1923	Dry	907	Cap rock and gypsum, 728–907 feet
Hindman *et al*	Smith	1	1923	Dry	889	Cap rock and gypsum, 451–889 feet
Hindman *et al*	Wilburn	1	1923	Dry	1,130	Aban. in cap rock
Hindman *et al*	Wilburn	2	1923	Dry	1,280	Aban. in cap rock
Humble Oil & Ref. Co.	Blaffer	1	1923	850	3,115	33.6 gravity oil
Humble Oil & Ref. Co.	Blaffer	2	1923	1,000	3,511	
Humble Oil & Ref. Co.	Blaffer	3	1923	Dry	2,914	Tested salt water
Humble Oil & Ref. Co.	Meyers	1	1923	85	3,606	33 gravity oil; tem., 79° F.
Republic Prod. Co	Fisher, E.	1	1923	Dry	3,095	Tested salt water
Texas Co	Scott	1	1923	Dry	4,635	Aban. in hard shale
Texas Co	Sheffield	1	1923	Dry	1,128	Aban. in cap rock
Texas Co	Sheffield	1	1923	Dry	2,237	Aban. in hard sand
Union Sulphur Co	DeWitt Barber	1	1923	Dry	1,400	Top of cap 930 feet; aban. in salt
Union Sulphur Co	Winfree, E.	1	1923	Dry	1,410	Top of cap 1,275 feet; aban. in salt
Union Sulphur Co	Winfree, M. C.	1	1923	Dry	682	Top of cap 495 feet; aban. in salt
Union Sulphur Co	Winfree, O. K.	1	1923	Dry	1,192	Top of cap 950 feet
Union Sulphur Co	Winfree, O. K.	2	1923	Dry	552	Aban. in cap rock

It rises to a maximum height of 83 feet and extends 45 feet above the surrounding prairie. The major axis is 12,000 feet long, extending N. 43° W., and the minor axis is 9,250 feet long. Erosion has been active, and the effect of surface drainage is clearly demonstrated in a number of gullies which extend in all directions away from the higher portions of the dome. Several erosional undulations have been formed which are entirely separate and distinct from, and have no bearing upon, the position of subsurface structure. There is, however, a general relationship between the shape and position of the mound as compared with that of the underlying dome. The highest portion of the hill lies only 1,250 feet northwest of the center of the dome and from the highest known structural displacement. The 3,500-foot contour on the cap rock corresponds closely with the outline of the base of the hill.

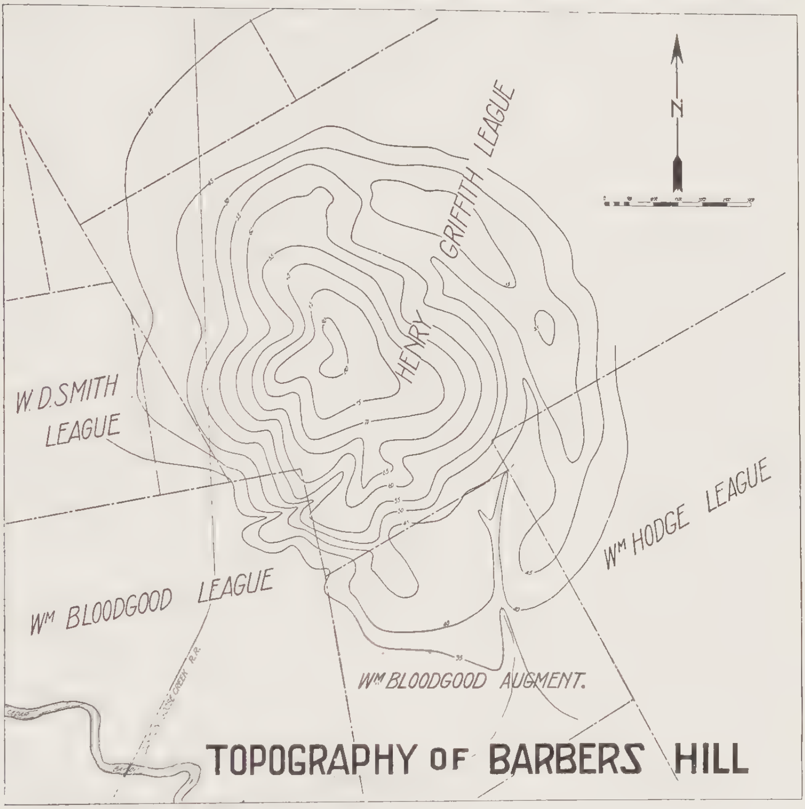

FIG. 1.—Topographic map of Barbers Hill

GEOLOGY

General description.—The surface at Barbers Hill presents very few exposures, and our knowledge of structural conditions must be gained essentially from a study of well logs, core samples, and drill cuttings. Cuts along the side of roadways near the top of the hill show 3 or 4 feet of mottled yellow clay, containing irregular patches and lenses of sandy clay, sand, and small calcareous concretions. The material apparently lies in a horizontal position but does not display bedding plains which can be used to define the attitude of the bed. Its texture and other physical characteristics are typical of the Beaumont clay.

A study of subsurface conditions shows the presence of an intrusive salt core capped by deposits of gypsum, anhydrite, and limestone. In the course of its development and growth, adjacent formations have been tilted or inclined at high angles, sloping in all directions away from the dome.

The upper extremity of the salt core is oval in outline, the top being essentially flat with slightly rounded edges sloping off at an angle of about 73° to an unknown depth. The southwestern edge, in the vicinity of the productive area, is faulted and irregular, showing an average dip of 59°. Core samples indicate that the salt plug is composed of almost pure rock salt, containing waves and bands of darker material, indicating flowage. Salt has been encountered in 10 wells; the Gulf Coast–Crown No. 1 Fisher entered rock salt at 1,813 feet and was abandoned at 2,500 feet still in salt. This is the greatest thickness of salt penetrated at Barbers Hill.

Cap rock.—"Cap rock" is a term generally applied to mineralized deposits adjacent to and above the salt plug. At Barbers Hill these deposits are largely composed of anhydrite, gypsum, and limestone, varying in thickness from 850 feet in the central portion to a few feet at the outer edges of the dome. They are extremely irregular and occur rather as lenses, pockets, and concretions, no two sections being alike. There is, however, a general arrangement of anhydrite below, limestone at the top, with gypsum between the two. The cap rock is generally porous and cavernous, containing variable amounts of sulphur, pyrite, and calcite deposited in crystal form throughout the porous spaces. Some of the crystals have rounded edges, indicating solution by circulating underground waters.

The upper portion of the cap rock is composed of very hard limestone. Inclusions of gypsum and anhydrite have been noted together with an occasional thin parting of gumbo.

The cap rock rises to within 350 feet of the surface, as shown by the well known as Keeble Trustee, Ben Fisher No. 1. This well is 2,250 feet south of the highest portion of the dome.

Structure of surrounding sediments.—Contour lines as shown on Figure 2 indicate the top of the cap rock below the surface. These lines express the shape of the dome rather than the amount of structural displacement.

The surrounding sediments are inclined at steep angles, sloping in all directions away from the salt plug. Dips of 45°–50° are common within the producing area on the southwestern portion of the dome, and core samples locally indicate dips of 80° or more from points adjacent to or near the top of the cap rock. Other points to the north, northeast, and southeast of the dome show dips of 65°–70°. The field is characterized by steep dips, and the surrounding formations have been sharply upturned or broken at the point of contact with the salt plug, although they are not elevated to much above their normal position around the periphery of the dome.

Faulting.—Circumferential step faults, the downthrow side being directionally away from the dome, are proved, and radial faulting has been noted on the southwestern side between the United Petroleum Company's No. 4 Richardson and the Gulf Coast–Crown No. 1 Fisher. The presence of faulting can be established at Barbers Hill, but, owing to the extremely complicated structural conditions in which decided changes occur within narrow limits, it is difficult to define a particular fault or zone of faulting with accuracy. Crushed and shattered zones are present usually at the point of contact between the salt plug and surrounding sediments, indicating that considerable movement has taken place under heavy pressure. Faulting at Barbers Hill is the result of displacement, induced by an upthrust from below.

Stratigraphy.—The lateral beds surrounding the dome are divided for convenience of description into the Oligocene, Fleming, and overlying sediments.

Oligocene fossils are reported to have been found in the Humble

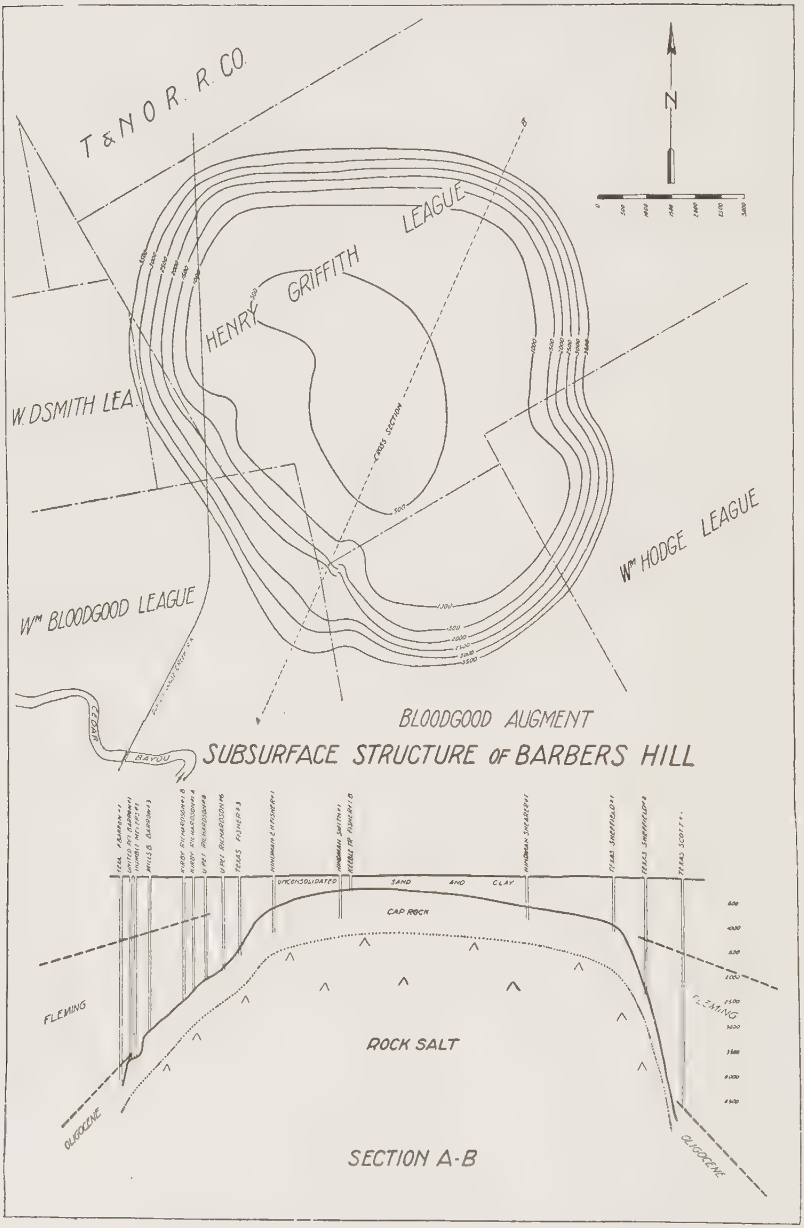

FIG. 2.—Map of subsurface structure of Barbers Hill with cross-section

Oil and Refining Company's No. 1 Meyers at 3,559 feet, indicating the top of the formation at this depth. This, to the writer's knowledge, is the only record of Oligocene formation at Barbers Hill.

The Fleming embraces the Miocene and a portion of the Pliocene formations. It is largely composed of calcareous clays with concretions, sands, and shales and is approximately 2,000 feet thick. These deposits are lenticular, extremely variable as to character, and change within narrow limits. The sandy members produce oil on the southwestern side of the dome.

Sediments overlying the Fleming and extending to the surface are of Pleistocene and Pliocene age. They consist, in part, of fluviatile and shallow-water deposits comprising a series of sands, gravels, and clays. These deposits are lenticular and extremely variable as to character. The thickness within the producing area averages about 1,400 feet, and the base of the formation dips at an angle of about 12°.

Geologic history.—The maximum structural displacement occurred at or about the transitional period between the Pliocene-Miocene deposition and continued with decreasing intensity to the time of Beaumont clay deposition. No observations have been made to establish the possibility of present-day growth.

Origin of the dome.—Barbers Hill is a typical salt dome. It was formed at about the same time and displays many of the characteristics common to other salt domes of the Gulf Coast district. Its origin is a subject upon which the writer has not observed any conclusive evidence to add to our present knowledge of salt-dome origin.

Origin of the cap rock.—The salt core of the Barbers Hill dome is intrusive, penetrating the surrounding formations. These formations have been cut or broken, permitting an intimate association of included waters with the salt plug. The water is under a static head, subject to minor movements of the dome, and has no doubt dissolved and redistributed a portion of the soluble material according to locally varying conditions and the laws of solubility. In view of this, it is believed that the mineralized material such as gypsum, anhydrite, cap rock, sulphur, etc., above the salt is derived from solutions as a precipitate or replacement, and that the character and extent of this material is governed by local conditions and subsequent movements of the dome. The presence of faulting within the cap rock indicates that movement must have taken place after the cap rock was formed.

OIL DEPOSITS

Production is confined to an area of about 100 acres, located as shown on Figure 3, and represents about 5.8 per cent of the total

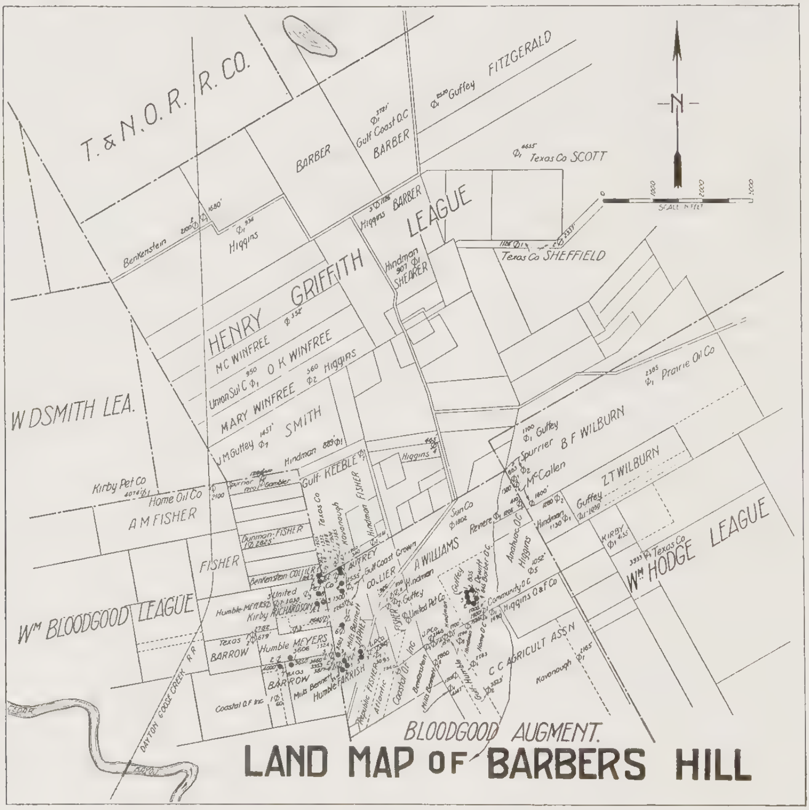

FIG. 3.—Property and well map of Barbers Hill

area of the mound. The oil is believed to originate within bituminous shales of the Oligocene and Miocene formations and to have later migrated into adjacent porous cap rock or sandy horizons. The majority of the so-called oil sands are really admixtures of sand, shale, and clay. They are lenticular, extremely variable as to character, and frequently change within narrow limits. Faulting is believed to play an important rôle in the accumulation of oil deposits and probably serves as an effectual barrier, retaining the oil on the downthrow side.

The character of oil varies considerably. Heavy oil of asphaltic base and thick consistency occurs in the upper portions of the cap rock and in sands adjacent to the cap rock. Oil of 17°–28° Baumé was produced from porous cap rock at depths of 1,065–2,230 feet within the older producing area. The gravity of this oil usually becomes lighter with depth, although exceptions to this rule have been noted. Oil produced from the edge sands around the dome range in gravity from 27° Baumé at depth of 2,730 feet to 39°.7 Baumé at 3,817 feet.

Analyses of oil.—The following analyses are characteristic of the oil produced at Barbers Hill:

TABLE II

TEST ON TWO 5-GALLON CANS OF MIXED CRUDE OIL

Gravity	34.0
Flash	Room temperature
Fire	Room temperature
Vis., 100	43
Color	Dark green
Pour	Below 0
Sulphur	0.33 per cent
Water	None
Odor	Naphtha
B.S	0.1 per cent

100 CC. DISTILLATION

Start	180
35 per cent off at	424
Overhead gravity	55.2
Color	Pure white
Doctor	N.G.
Bottoms	65 per cent
Gravity	25.4
Color	Dr. gr.
Pour	Below zero

Production curves.—A production curve has been prepared showing total monthly production from October, 1918, to December, 1923 (Fig. 4). Superimposed upon this curve is a second curve in broken lines, which indicates the fluctuations in price of crude oil.

TABLE III

Cuts	Percentage	Temperature	Gravity	Flash	Fire Test	Viscosity	Color	Pour
1....	5	268	70.9	R.T.	R.T.	....	S.G.	Below 0
2....	10	315	62.8	R.T.	R.T.	....	S.G.	Below 0
3....	15	343	58.2	R.T.	R.T.	....	W.W.	Below 0
4....	20	360	53.6	R.T.	R.T.	....	W.W.	Below 0
5....	25	360	52.0	R.T.	R.T.	....	W.W.	Below 0
6....	30	368	49.0	R.T.	R.T.	....	W.W.	Below 0
7....	35	370	44.1	90	95	29	W.W.	Below 0
8....	40	378	40.6	105	130	30	W.W.	Below 0
9....	45	390	37.2	140	165	31	Lt. straw	Below 0
10....	50	410	33.6	190	205	33	Lt. straw	Below 0
11....	55	430	31.2	220	260	36	Lt. straw	Below 0
12....	60	459	29.4	260	280	41	Straw	Below 0
13....	65	485	28.0	290	310	52	Yellow	Below 0
14....	70	512	26.5	310	345	69	Yellow	Below 0
15....	75	545	24.8	355	400	135	Brown	Below 0
16....	80	515	23.2	395	415	262	Dk. br.	Below 0
Btms..	20	....	18.4	510	575	238/212	Black	Plus 20

Estimated finished products: gasoline, 30 per cent; naphtha, none; kerosene, 15 per cent; solar oil, 35 per cent; bottoms, 15 per cent; fuel loss, 5 per cent.

TABLE IV

MIXED CAP-ROCK OIL; GRAVITY, 19°–20°

	Gravity	Flash	Viscosity at 100	Cold Test
1st..........	10°–29°.7	155	10	....
2d..........	10 –lost	....	....	....
3d..........	10 –22.9	240	163–100	0
4th..........	10 –19.5	290	153–100	0
5th..........	10 –17.2	360	712–100	10
6th..........	10 –16.2	405	657–100	25
7th..........	10 –16.0	360	125–210	35
8th..........	10 – 1.59	245	126–210	30

Bottoms, 20 per cent.

A total of seven distinct peaks tell diagrammatically the story of the Barbers Hill production. The first three occurred in 1918, 1919, and 1920 and represent activities in the cap-rock field. The last four are records of edge-sand production during the years 1921, 1922, and 1923.

Maximum production for the field was reached in October, 1922. During this month a total of 53,800 barrels was produced largely from two wells: Mills Bennett, Japhet No. 1, and Japhet No. 2. The decline was very rapid, and within four months production had decreased 78 per cent.

The performance of individual wells is generally governed by the character of producing horizon, mechanical condition of the well, and method of operation. Cap-rock production is usually lower initially and less rapid in decline than production from edge sands.

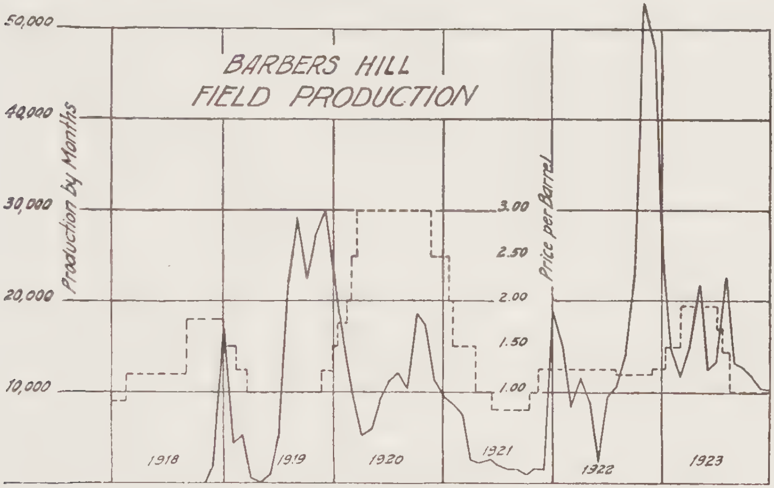

FIG. 4.—Curve showing Barbers Hill Field production

Figure 5 shows production by months of Mills Bennett, E. Barrow No. 1, and Mills Bennett, Japhet No. 1.

Drilling and production methods.—All wells are drilled by the rotary method, using a fish-tail or roller bit as the occasion demands. Casing is usually set in gumbo or rock immediately above the producing horizon with from one to four joints of 80-mesh screen in the producing sand. The initial production of flowing wells is usually free from water or emulsion, but the oil from most of the wells eventually requires dehydration. The cost of drilling and completing a 3,000-foot well, including all items of expense, approximates $27,000.

SULPHUR

Showings of pure crystallized sulphur were found in a few wells along the southern slope of the hill. Jos. Reviere and Company drilled through sulphur and gypsum at a depth of 1,200 feet in their Reviere No. 1. Hindman *et al.*, Chambers County Agricultural Association No. 1, records sulphur, gypsum, and oil in hard rock at a depth of 1,380 feet. Community Oil Company's Monongahela Trust No. 1 obtained a little sulphur at 1,900 feet. Other wells of the vicinity are said to have shown sulphur while drilling through the cap rock.

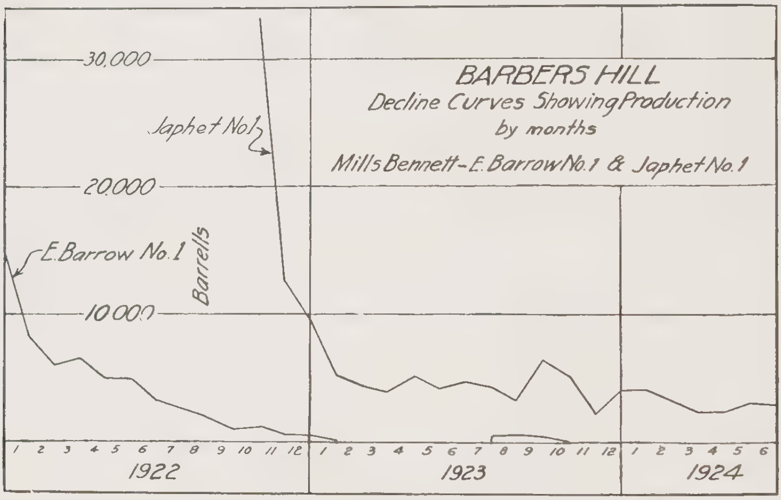

FIG. 5.—Curve of production decline, Barbers Hill Wells

All drilling prior to 1922 was primarily for the purpose of obtaining oil, and as a result very little was learned about the actual sulphur content of the formations penetrated. In 1922 the Union Sulphur Company and Sam Hindman *et al.* drilled ten wells on the dome in search of sulphur. These wells penetrated the cap rock for a considerable distance.

The sulphur occurs near the top of the cap rock and extends downward for several hundred feet. It is usually in the form of disseminated crystals deposited within porous limestone. The total sulphur content as indicated by core samples is not sufficient to warrant commercial exploitation.

CONCLUSION

It is apparent that the oil recovered at Barbers Hill has not been sufficient to satisfy the expenditure. Wells within an area outlined by the 1,000-foot contour, as shown in Figure 3, usually obtain shows of heavy, viscous oil from the top of the cap rock and in sands above the cap rock. The sands are thin, lenticular, and apparently broken. These horizons generally carry salt water containing relatively high percentages of hydrogen sulphide and very little oil.

Conditions favorable for the retention of oil occur within a small area on the southwestern portion of the dome. All attempts to extend this area or to locate a similar pool on other flanks of the dome have been unsuccessful. The steep dips encountered by these tests indicate that if additional production is found the oil will occur within a narrow strip surrounding the edge of the salt plug.

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GOOSE CREEK OIL FIELD, HARRIS COUNTY, TEXAS

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ABSTRACT

The Goose Creek oil field in Harris County, Texas, first received attention in 1906, when its possibilities as an oil field were recognized by Mr. L. P. Garrett and Mr. Lee Hager, independently of each other. To these gentlemen credit is due for the discovery, although commercial production was not obtained until after much drilling by numerous enterprises. The stratigraphy is characterized by the unconsolidated nature of the sand, gumbos, and shales, which are penetrated in drilling to a depth of 5,000 feet. The structure at Goose Creek is a low dome, with no evidence of any salt core or salt plug such as distinguish most Gulf Coast fields. The field has produced about 50,000,000 barrels of oil from about 1,000 acres, production coming from sands at depths of from 1,000 feet to 4,200 feet. Recent subsidence of the surface over the producing area is explained by the removal of oil, gas, water, and sand, which permits a closer orientation of the sand grains in the producing horizons.

LOCATION

The Goose Creek field is located in the southeast corner of Harris County, Texas, approximately 25 miles southeast of Houston, on San Jacinto Bay. The field was accessible only by water or dirt road until 1917, when a spur, known as the Goose Creek & Dayton Railroad, was built from the main line of the Southern Pacific at Dayton, Texas, to the town of Goose Creek.

HISTORY

In 1906, a fishing party, composed of Messrs. L. P. Garrett, R. A. Welsh, and R. T. Rue, noticed the occurrence of gas seeps in the vicinity of Goose Creek. The men composing this party understood fully the significance of these indications, and a careful investigation resulted in the location of numerous gas seeps and paraffin beds over the area which is now the Goose Creek oil field.

Satisfied that the indications warranted exploitation, Messrs. Welsh and Rue formed the Goose Creek Production Company and proceeded to procure leases upon the land surrounding Goose Creek. Upon examining the records, it was found that Mr. Lee Hager had already secured leases upon the Sweet and Briggs properties. Evidently, he too had observed the indications and satisfied himself with the possibilities of the prospect, as he has consistently done at nearly every coastal dome. The remaining lands were blocked up in the name of the Goose Creek Production Company.

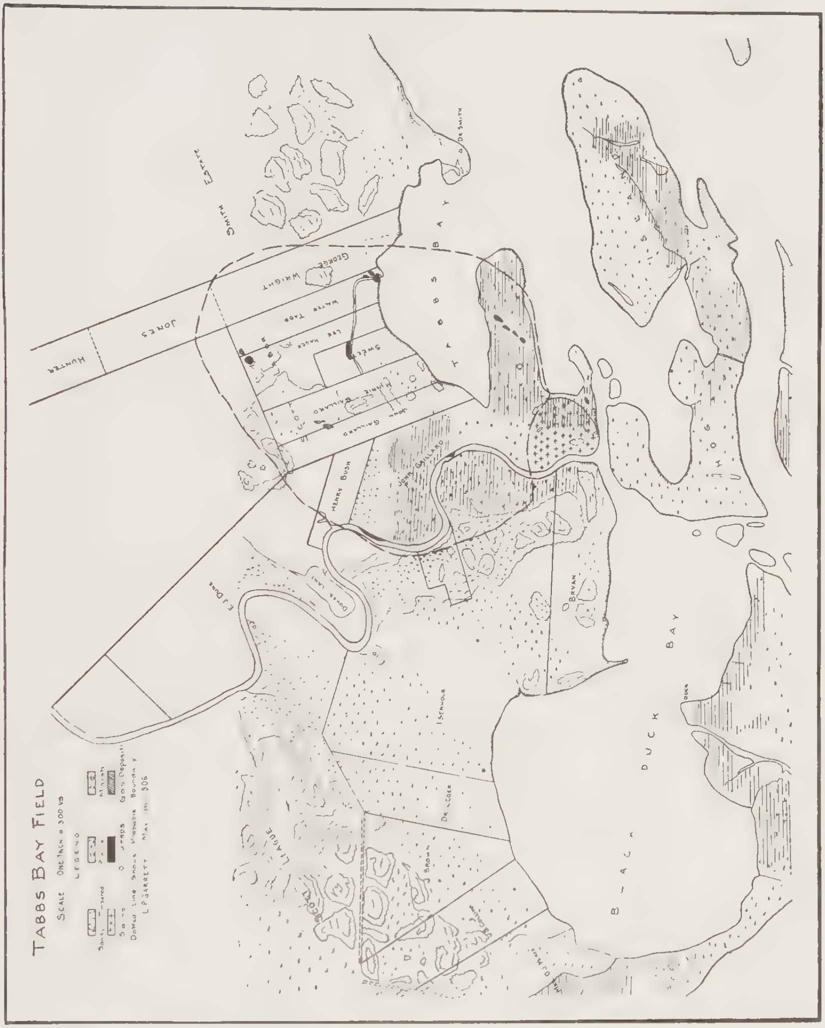

FIG. 1.—A map of Goose Creek field made by Mr. L. P. Garrett prior to discovery

At this time, 1907, Mr. L. P. Garrett, employed by the Rio Bravo Oil Company, made the first favorable report to his company upon the possibilities of Goose Creek becoming an oil field. Accompanying this report was the first map of this area (Fig. 1), which shows the location of gas seeps and paraffin beds, together with the outline of the probable area of production. The productive area delineated by Mr. Garrett on this map coincides very closely with the field as it exists today, and certainly he is to be commended upon the accurate interpretation of the meager indications found in 1907, which has led to the development of one of the Gulf Coast's greatest producing oil fields.

It has been learned from reliable sources that at about this time Mr. Patillo Higgins had observed the presence of gas emanations in this territory. It is thought, however, that he had seen the gas seeps in the vicinity of Hog Island. What significance he attached to it, the writer has been unable to learn.

DEVELOPMENT

The Goose Creek Development Company commenced drilling the first well in December, 1907. This well was located on the J. Gaillard tract, only a short distance north of the old John Gaillard home, midway between the farthest north-and-south and east-and-west gas seeps. At a depth of 700 feet a showing of oil was encountered, but drilling was continued. At the end of two years, the drill had reached the depth of 1,700 feet and the well was abandoned. In June, 1908, the Goose Creek Production Company started their second well. It was also located on the Gaillard land, and very near what was known as the Rucker 4-acre tract. This well was completed as an 800-barrel well at a depth of 1,600 feet, the first to produce oil in the Goose Creek field.

In 1909, the Goose Creek Production Company sold their entire holdings to the Producers Oil Company, the consideration being $50,000 in cash and a one-fourth overriding royalty. During the next few years the Producers Oil Company drilled ten or fifteen wells.

The results of these tests were very discouraging, and the Producers Oil Company surrendered the leases to the original holders. In a short time thereafter, the leases found their way into the hands of various oil companies, wildcatters, and speculators. The area, drilled full of dry holes, with an occasional small pumper, struggled along under the shadow of its past disappointments for six years.

On August 22, 1916, the American Production Company, drilling on the Gaillard tract, 600 feet north of the shallow production, and financially "on their last legs," encountered a sand at 2,030 feet. The bit had hardly penetrated the sand when the well came in flowing wild, at a rate estimated to be 10,000 barrels per day. This spectacular discovery inaugurated a period of active development, which has continued up to the present time. Prior to the discovery of the 2,000-foot sand, practically all of the production was obtained from sands lying at shallower depths. Several wells had been drilled to greater depths than 2,000 feet before the American Production Company's discovery, but practically all of these were located beyond the productive limits of this sand.

During this period of development at Goose Creek, several exceptional wells were completed. The Simms Oil Company brought in their Sweet No. 11 in August, 1917, from a depth of 3,027 feet the well flowing wild for several days, at the rate of 35,000 barrels of oil per day, with a great amount of sand. Finally it sanded up, leaving the surrounding area covered with a blanket of oil-saturated sand and mud 1 to 3 feet in thickness. The Humble Stateland No. 10 was completed November 10, 1922, at 4,292 feet, with an initial production of 3,200 barrels, and has produced approximately 1,000,000 barrels of oil to date and is still flowing at the rate of 1,200 barrels per day. The Gulf Production Company's Chapman-Bryan No. 1, still flowing at the rate of 900 barrels per day, was completed March 30, 1922, at a depth of 4,200 feet. This well has produced 1,237,000 barrels of oil to date.

It will be seen from the production curve (Fig. 2), that the production of the field gradually climbed from 42,000 barrels in 1916 to over 9,000,000 barrels in 1918, where the peak of production was reached. The decline in production has been very irregular, rising as the deeper sands were developed, and falling as the flush production was given up. At the present time, the production is on the decline slope, and has nearly reached the point where the curve tends to approach the horizontal. Its projection into the future is conjectural, but undoubtedly the beams will be running at Goose Creek for a good many years to come, as evidenced by Spindletop, with its single horizon still producing 1,000 barrels daily after twenty-three years.

TOPOGRAPHY

At Goose Creek there is no topographical elevation or depression to indicate the presence of a dome, and only the closest observation and the greatest perseverance led to the discovery of its treasures.

STRATIGRAPHY

A well, drilled in the center of the field, encounters the following strata: The first 50 to 100 feet is composed of soft surface sands and clays of recent deposition. The bit then enters red, gray, blue, and brown shales, and clays intermittently separated by strata of water sands, belonging to the Pliocene. At a depth of approximately 1,000 feet the first oil sand is encountered. Below this, the predominating color of the shales and clays is still red and pink, but the sands are harder and carry an abundance of brackish water. From 2,300 to 2,600 feet a horizon made up of alternating sandstones, sands, gumbos, and shales is encountered. The majority of the sands carry oil, but occasionally a stray water sand occurs, causing the usual

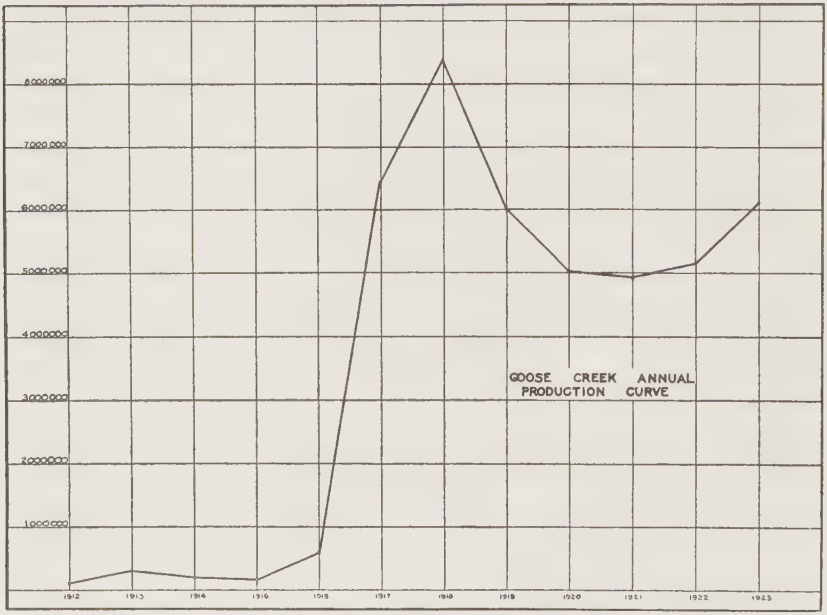

Fig. 2.—Curve of annual production, Goose Creek oil field

trouble in the completion of an oil well. Below this producing horizon, numerous water sands, approximately as salty as sea water and separated by red and blue gumbo, are passed through. The next producing zone extends from 2,800 to 3,100 feet. In this zone, the sands are probably thicker than in any other producing horizon, at places attaining a thickness of 80 to 100 feet, and they are of greater areal extent than any other producing sands in the field.

At 3,300 feet and again at 3,600 feet, sands are passed through which have furnished exceedingly good wells. Below this depth, the formations take on a darker hue, the shales and gumbos having changed from blue, pink, and red to dark blue and dark gray. At just what depth one passes from Miocene to Oligocene is not definitely known, but it is evident from fossils obtained that the production above 3,900 feet is not older than Miocene.

For the next few hundred feet, an almost unbroken series of dark shales is found, and at 4,200 feet the deepest producing sand is reached. This producing horizon is really a sandy phase of the shales, rather than a true sand stratum. At this depth, paleontologists report Oligocene fossils. The oil is lighter in gravity, the waters are more than twice as salty as sea water, and the sand is very irregular in its areal extent. There appear to be a series of sand lenses, which lie promiscuously here and there under the field, failing entirely in certain localities and thickening to 30 or 40 feet in others.

What Goose Creek holds in store below this depth, can be revealed only by the drill. However, if this field is a true salt dome, and so far there is nothing to indicate that it is not, the possibilities for deeper production should be exhausted only when the salt core itself is encountered. The following deep wells have already been drilled without success:

Gulf Production Company, John Gaillard Fee No. 15, to 5,002 feet
Gulf Production Company, Beaumont Petroleum Company No. 23, to 5,000 feet
Gulf Production Company, Isenhour No 6, to 4,833 feet
Gulf Coast Oil Corporation, Gaillard No. 35, to 4,781 feet
Humble Oil and Refining Company, Gaillard No. 48, to 4,708 feet

Experience in the salt-dome territory has taught that in many cases a dry hole in a proven field condemns only a very small area surrounding the well itself.

STRUCTURE

We have not sufficient data to determine when the subterranean agencies began their movement in this locality, but it is evident that the movement was still in effect as late as Pliocene time. Whatever this force may have been, the upward intrusion of the salt core, or the crystallization and deposition of salt by ascending waters, the resultant force must have been upward, elevating the beds and form-

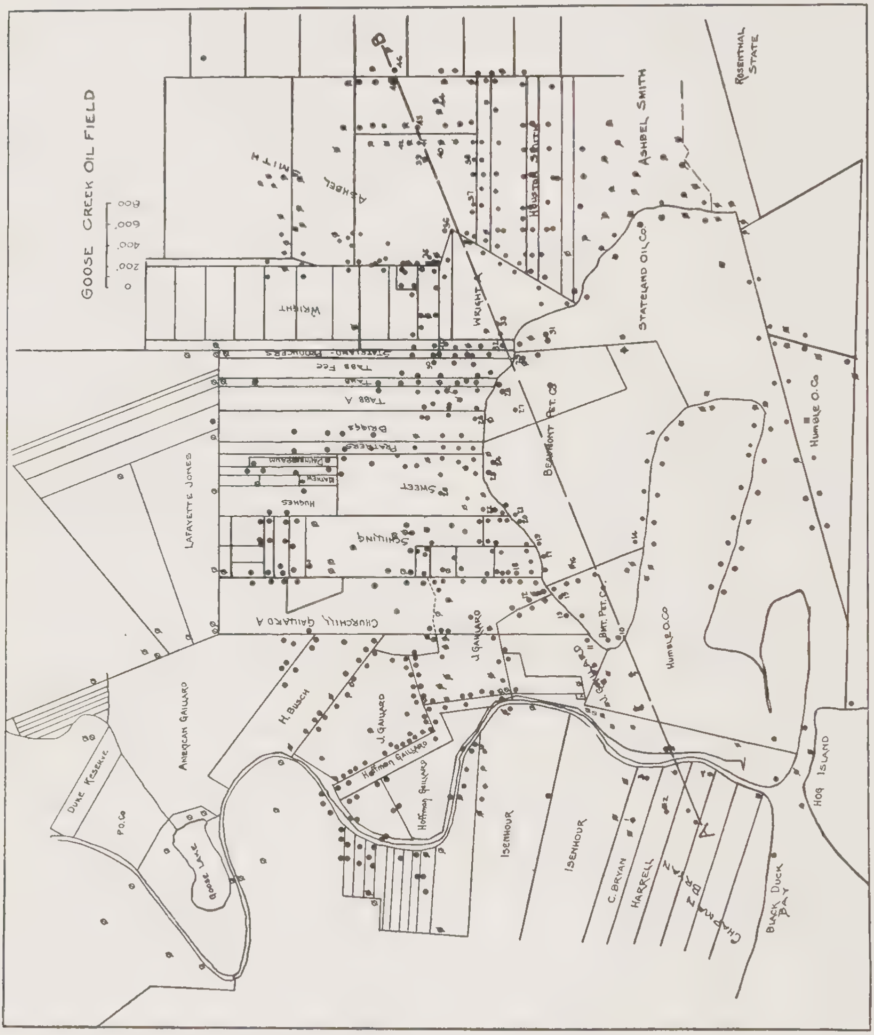

FIG. 3.—Map showing location of wells, Goose Creek oil field

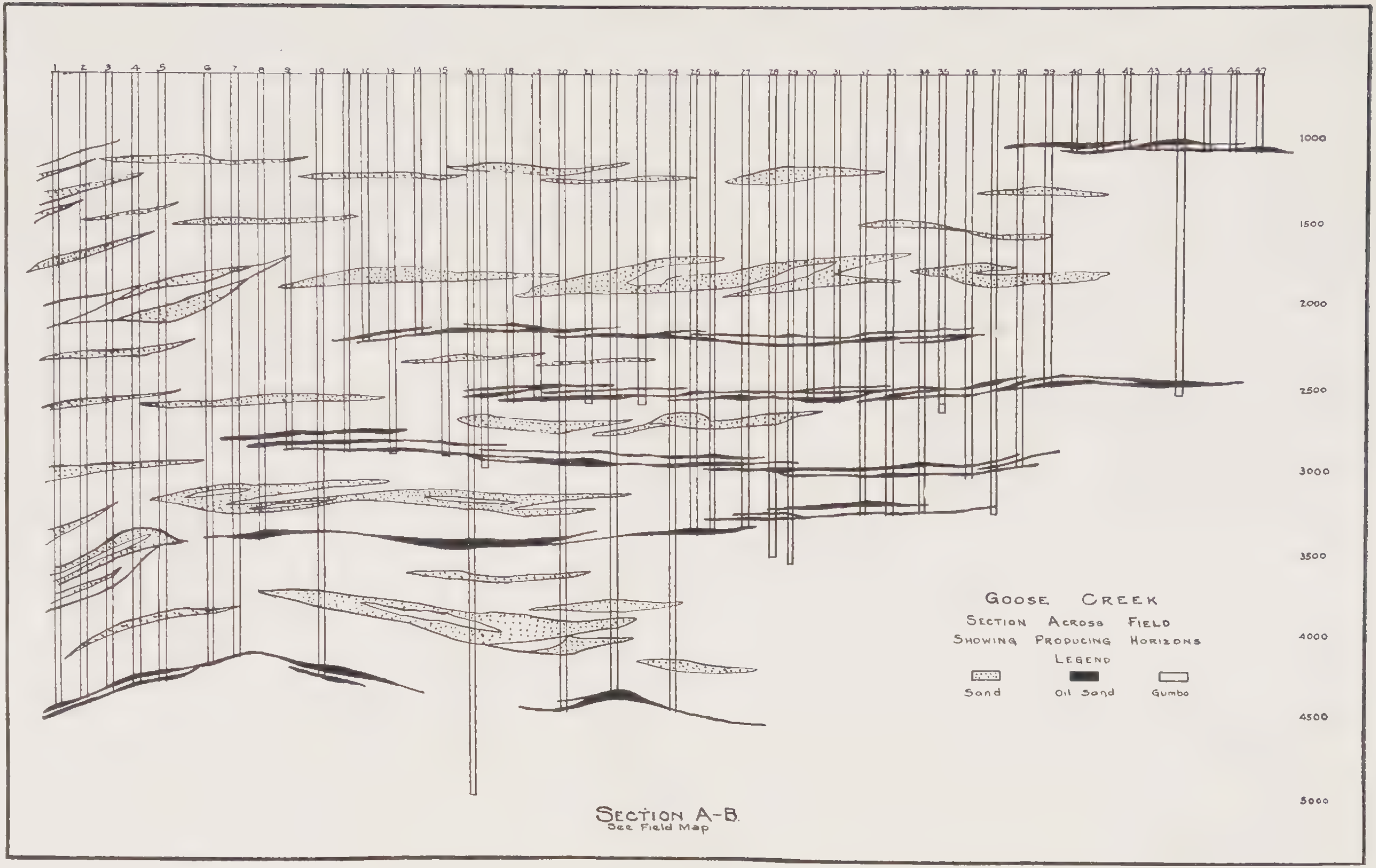

FIG. 4.—Map showing northeast-southwest section across Goose Creek oil field

ing a circular reservoir, which has proved very efficient for the accumulation of petroleum. This force was of such magnitude that it has evidently destroyed, to a great extent, the continuity of the soft unconsolidated beds, leaving the sands and clays in irregular masses and lenses, and accounting in a way for the difference in thickness and character of the formations, and also in the variation in production of adjacent wells. The cross-section of the field (Fig. 4) gives an idea of the various producing horizons, and also shows the lenticular nature of the sands.

Detailed correlation in this field is very difficult on account of the lack of continuity of the beds, and can be arrived at only in a general way. There is, however, a marked dip to the east from the Wright "A" lease, extending eastward through the Houston-Smith lease. A pronounced north dip becomes evident a few hundred feet south of the south line of the Jones tract, forming the northern flank of a gentle arch, which extends to the south through the field and terminates in a very gentle dip to the south, in the vicinity of Hog Island.

The thought is ever present that Goose Creek, Edgerly, Orange, and Welsh, having no known salt cores, might be classed as true domes independent of salt-dome movement. This is a subject too broad to be discussed in this paper, but it may be said that in every case these fields have taken on the typical circular form of the salt dome. The position of the basal Oligocene at both Goose Creek and Orange indicates a vertical uplift of several hundred feet at these localities, a much greater displacement than revealed in the structure of the overlying strata.

The salt waters in these fields increase uniformly with depth. This might also be true in any area, but in no area outside the salt-dome fields does the salt content equal 12 per cent, which is attained at both Goose Greek and Orange. In fields of the Goose Creek, or deep-seated, type, it has been observed that below 1,000 feet the waters increase in salinity at the rate of 1 per cent salt for every 180 feet of depth.

CHARACTER OF OIL

The oil produced at Goose Creek is of a dark green color, ranging in gravity from 22° to 27° Baumé, and possessing the odor of cedar rather than the hydrogen-sulphide odor so characteristic of the cap-rock fields. Practically all of the producing sands above 3,600 feet produce an oil varying in gravity from 22° to 24° Baumé, while the sands below this depth produce a lighter, or 26° to 27° Baumé oil. A refining test of a typical Goose Creek oil is given in Table I.

TABLE I

Analysis of Goose Creek Crude Oil

Gravity: 23.2
Color: Dark green
Sulphur: 0.117
Boiling-point: 420

Per Cent	Degrees Fahrenheit	Gravity Baumé
10	464	32.5
20	510	30.2
30	548	28.5
40	586	26.9
50	630	25.5
60	684	24.2
70	700	23.8
80	704	24.6

PRODUCTION STATISTICS

At the close of 1923, Goose Creek had produced a total of 47,760,000 barrels, and in Figure 2 is shown the production curve for the entire field, from the year 1912 to January 1, 1924. The total productive area at present consists of approximately 880 acres, giving an average total production to date of 54,272 barrels per acre, with the field still producing 13,500 barrels per day.

DRILLING METHODS

The rotary method of drilling is exclusively used in this field. It is the general practice to set from 400 to 800 feet of surface 10-inch casing. A $9\frac{7}{8}$-inch hole is then carried to the last gumbo above the sand to be tested. If this depth is not known, a rat-hole, or small hole, is carried in advance of the larger hole, until the sand is encountered. The hole is then reamed to the last gumbo above the pay, and 6-inch casing set. Drilling is then resumed with $5\frac{7}{8}$-inch bit. When the hole is drilled into the sand to the desired depth, $4\frac{1}{2}$-inch liner and screen is set, the liner being sealed well up in the 6-inch casing. In wells located in the bay, as a rule, a few joints of surface $15\frac{1}{2}$-inch casing is set, followed by 500 to 1,000 feet of 10-inch. The hole is then completed as described above. Cementing of casing is not common, as a water-tight seat is usually assured by virtue of the tough, plastic nature of the gumbo and also by the cavey character of the overlying beds, which, immediately upon the cessation of the mud circulation, close in against the casing.

The deepening, re-working, sidetracking, and plugging back of wells is common in Goose Creek, general rotary practice governing these operations. Coring of the sands was begun at Goose Creek in 1915. Prior to this time, practically no coring was attempted Oil sands were indicated by the showing on the ditch, or by cuttings caught in a receptacle at the mouth of the flow pipe, and it was believed that an oil sand which would not show oil on the ditch was not worth testing. This belief has undoubtedly often been responsible for failures where a good oil well might otherwise have been completed. The coring device generally used is a short piece of 3- or 4, inch pipe, toothed at one end, and is commonly known as a basket, or barrel. This barrel is screwed to the drill stem and lowered into the well, where it is rotated as an ordinary bit, with just sufficient weight upon the teeth to allow them to cut their way into the formation. When the desired length of core is drilled, the weight upon the teeth is increased, causing them to fold in toward the center, thus completely encasing the core. The drill stem is then pulled from the well, the teeth sawed off, and the core examined and analyzed to ascertain its oil or salt-water content.

Goose Creek is the most modernly equipped field in the Coastal district. Plants of the various companies supply electrical power for the pumping of wells, treating of oil, etc. Practically every well in the field is pumped by electric power. The Gulf Production Company has a 1,500-kilowatt plant located in the field. The Humble Oil and Refining Company supply power to the field from their Baytown plant.

The drilling cost of wells at Goose Creek has averaged approximately $10 per foot for wells 2,400 to 3,500 feet deep. At the close of 1923, in the neighborhood of 900 wells had been drilled within the comparatively small area of 880 acres, with an average production of 53,000 barrels per well.

SUBSIDENCE OF SURFACE OVER PRODUCTION AREA

Since the active development of Goose Creek in 1916, there has been a marked subsidence of the area lying over the center of the field. During the years 1916 and 1917, the surface of Gaillard Peninsula (as it was then known) was a land area which stood ½ to 2 feet above the mean high tide. Material was transported to the wells located upon the peninsula over shell and plank roads. Today, this entire land area lies submerged under possibly 3 feet of water. At no place could a subsidence be more clearly noted. In many places, along the north and south limits of the field, miniature faults may be seen plainly, and they may be traced for considerable distances. Recent elevations, compared with those determined by the U. S. Geological Survey of 1916, show the greatest subsidence, of 2.2 to 2.7 feet, to have occurred over the area of greatest production, with the surrounding area gradually resuming its original elevation a short distance beyond the limits of production.

The explanation offered by the writer for this recent land subsidence is that, due to the enormous flow of gas, oil, and water in the wells, a movement or flow of the fluids in the sands caused a readjustment and closer packing of the sand grains. The overlying beds, consisting of comparatively soft clays, shales, and sands, gave way and settled to a lower position because of the readjustment of the underlying sands.

THE SOUTH DAYTON SALT DOME, LIBERTY COUNTY, TEXAS[1]

W. F. BOWMAN
Houston, Texas

ABSTRACT

The South Dayton-Liberty salt dome is a characteristic Gulf Coast salt dome. The salt core is 1½ by 2½ miles in diameter and comes to within 500 feet of the surface. The major diameter strikes N. 30° E. The cap is 150–250 feet thick and consists of gypsum and anhydrite with a thin capping of limestone. The beds penetrated in drilling are Jackson to Recent in age. The top of the dome has been well tested; although shows of oil and sulphur were had, neither was found in commercial quantity. The lateral sands have been tested only by three moderately deep wells and still offer possibilities of discovery of production.

INTRODUCTION

Most of the data for this paper was collected during 1922 by the writer and other members of the geological department of the Rio Bravo Oil Company under the direction of Dr. E. T. Dumble and Mr. John R. Suman, and is published with their permission. The history of development was compiled largely from periodicals published at the time of the early exploration around the dome. Early reports of the Rio Bravo Oil Company contained much information. The companies which drilled the different wells have been very liberal with such of their well logs as were preserved. Logs of many of the early wells were never kept. Early operators have given some records from memory.

LOCATION

The South Dayton salt dome is in the south central portion of Liberty County, Texas, about 38 miles northeast of Houston. It is in the Trinity River bottoms about 2–5 miles south of the Texas and New Orleans Railroad (Southern Pacific lines). Liberty, on the east side of Trinity River, and Dayton, on the West, both on the Texas and New Orleans Railroad, are the nearest towns. The river flows across the center of the dome, and accordingly the northeast half is most accessible from Liberty and the southwest half from

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[1] Known equally well as the South Liberty or the South Liberty–Dayton salt dome.

Dayton. Most of the area is subject to overflow, and from two to five months each year it is practically impossible to get to the area at all.

Other domes in the region are Hull, 12 miles; Batson, 18 miles; Saratoga, 22 miles; and Sour Lake, 25 miles—all in a northeastward direction. Davis Hill is 18 miles north; North Dayton, 12 miles northwest; Humble, 25 miles west; and Barbers Hill, 12 miles southwest. All of these domes have been found productive except Davis Hill and South Dayton. All of the productive domes have yielded large quantities of oil with the exception of North Dayton and Barbers Hill.

HISTORY

The finding of oil on Spindletop salt dome in 1901 started a search for salt domes throughout the Gulf Coast country. South Dayton almost immediately attracted attention. The indications in this area were sulphur springs, gas escapes, and oil seepages. The most important of these was a spring located near the south end of Duncan Lake in the southwest portion of the Matthew G. White survey. It is said that bubbles of gas as large as one's fist could be seen coming up through the deep-blue sulphur water. Oil showings occurred also on the water. Similar indications were observed to the southwest across the river.

Because of these favorable signs, a company organized by Messrs. Bullard and Wilson during the year 1902 drilled three wells in the Bullard and Wilson subdivision on the west side of the river. Good showings were encountered in each test. Well No. 3, which was completed later by the Liberty–Marble Falls Oil Company in 1905 at a depth of 419 feet, was thought for a while to be a gusher from a depth of 400 feet. A rush was made to the area, and the prices of acreage soared to high figures, but sulphur water and salt water soon drowned out the oil and dampened the ardor of the promoters.

In 1904 the Sulphur Springs Oil Company was organized by Mr. E. B. Pickett, Sr., and Judge C. F. Stevens, and this company started two wells. The first was drilled near the sulphur spring in the southwest corner of the Matthew G. White survey. In order to keep other leases from expiring, the hole was abandoned at 400 feet and the rig skidded a few hundred feet south where a second well was started. These locations were made here because of the gas and oil showings in the sulphur spring.

In 1905 the Liberty–Marble Falls Oil Company was organized and took over both the Bullard-Wilson and the Sulphur Springs Oil Company holdings. No. 2 of the Sulphur Springs Oil Company, east of the river, was completed to a depth of 821 feet. This well encountered gypsum at about 500 feet and is reported to have gone through a very good showing of sulphur at around 600 feet.

Encouraged by the results of these first five wells, a number of companies were organized and numerous wells were drilled. Practically all of the wells encountered good showings of oil, but these were soon drowned out by salt and sulphur water. By the end of 1906, in addition to the Liberty–Marble Falls Oil Company, the Heywood Oil Company, the Pickett-Henry Company, and the Paraffin Oil Company had started operations in the field. Seven wells had been completed on the east side of the river and ten on the west. With the exception of the Liberty–Marble Falls No. 1 Bullard-Wilson subdivision and the Heywood Oil Company well east of the river, which were 1,200 and 1,500 feet deep, respectively, none of the wells were over 900 feet deep.

In 1907 two more wells were drilled, one on the east side of the river for sulphur and one on the west side for oil. On account of the very favorable reports of solid sulphur encountered in the Liberty–Marble Falls Oil Company well which had been taken over from the Sulphur Springs Oil Company, the American Sulphur Company of St. Louis, headed by Dr. A. L. Lyons, started the drilling of five wells. The first was located several hundred feet northeast of the Liberty–Marble Falls Oil Company well. In this well considerable sulphur was encountered, but it is said was disseminated in small pieces throughout gravel. The second well was drilled only a short distance from the old Liberty–Marble Falls well, and practically the same conditions were found. Their Nos. 3, 4, and 5 wells did not encounter either oil or sulphur in commercial quantities.

By the end of 1916 a large number of shallow wells had been drilled in search for cap-rock oil. This was a heavy oil and seemed to be in a thin scum or layer over the salt water. Numerous wells set casing above it and then drilled in, but in each case the salt water broke through the oil. Several of these wells are still flowing salt and sulphur water.

In 1917, after deep oil had been found on the salt domes in other portions of the Gulf Coast area, the Empire Gas and Fuel Company started a series of tests for deep oil around the dome and drilled, in all, fourteen wells. Of these, four encountered cap rock and salt and were abandoned at shallow depths. Their first deep test was drilled on the J. Reviere land in the M. G. White League. This well encountered an oil sand at 2,876 feet which was about 20 feet thick. Strainer was set and the well blew out and threw oil over the derrick, but the strainer sanded up and the production was never brought back. The oil was about 28° Baumé gravity. Because of this show, the company bought 10 acres of the Beard tract about 1 mile to the east, at a price of $12,500. A well 3,485 feet deep was drilled on this tract, but no encouraging results were obtained. During this time the Empire Gas and Fuel Company had started drilling on the west side of the river. Two wells were drilled on the Charles Wilson land to a depth of about 3,000 and 3,600 feet, respectively. Three were drilled on the Jackson land to depths of less than 1,500 feet. One of these wells pumped oil for several weeks, but was not commercially profitable at the prices then prevailing. Three deep wells were drilled on the Welder land, but though each had showings, nothing of importance was encountered. In 1920 the Empire Gas and Fuel Company withdrew from the field without having developed any production. Their operations together with the drilling of other companies have pretty well outlined the dome.

In 1923 the Union Sulphur Company began a series of tests on top of the dome in search for sulphur. To the present time they have completed six and are drilling two others, but the results of these tests have not been made public. A deep test for oil is being made on the northeast side of the dome by the South Liberty Oil Company. This test is only about 50 feet south of the J. Reviere well drilled by the Empire Gas and Fuel Company and has encountered about the same oil showings as were obtained in that well.

Drilling which has not been referred to heretofore and which helps to outline the dome was that of Grandberry and Staiti on Block 10 of their own subdivision and that of Hamilton *et al.* on the Condit land in the southwest corner of the David Minchey survey. The Grandberry and Staiti well went about 1,750 feet without encountering dome material. The drill stem was twisted off and the hole lost without any tests having been made. Little or nothing has been learned about the Condit well except the reported depth, 2,670 feet. It is said that no dome material was encountered.

To the present about fifty-six wells have been drilled in the field. Thirteen of these were drilled off the area of the salt; the others were shallow cap-rock tests.

TOPOGRAPHY

Trinity River flows across the center of the dome from north to south. Most of the dome lies in the bottom lands of the river, and the topography is mainly typical of the Trinity bottoms (Fig. 1). A low ridge encircles the north, northeast, and east sides of the dome. The highest elevation along this ridge is on the northeast edge of the dome where it reaches 34 feet. The average bottom lands range between 10 and 18 feet above sea. This ridge is probably due, in part, to doming.

The bottom lands in the vicinity of the dome are about 4 miles wide. The bank on the west side opposite the dome is some 50 feet high and forms an east-facing scarp. On the east side the bank is not so regular but is well defined. The banks are typical of the natural levees along east Texas rivers.

STRATIGRAPHY

The South Dayton salt dome lies within the area of the Beaumont clays, about 8 miles south of the contact of these clays with the underlying Lafayette. The material exposed at the surface over most of the dome is silty and loamy alluvium from Trinity River. Along the ridge on the northeast edge of the dome and near the Reviere

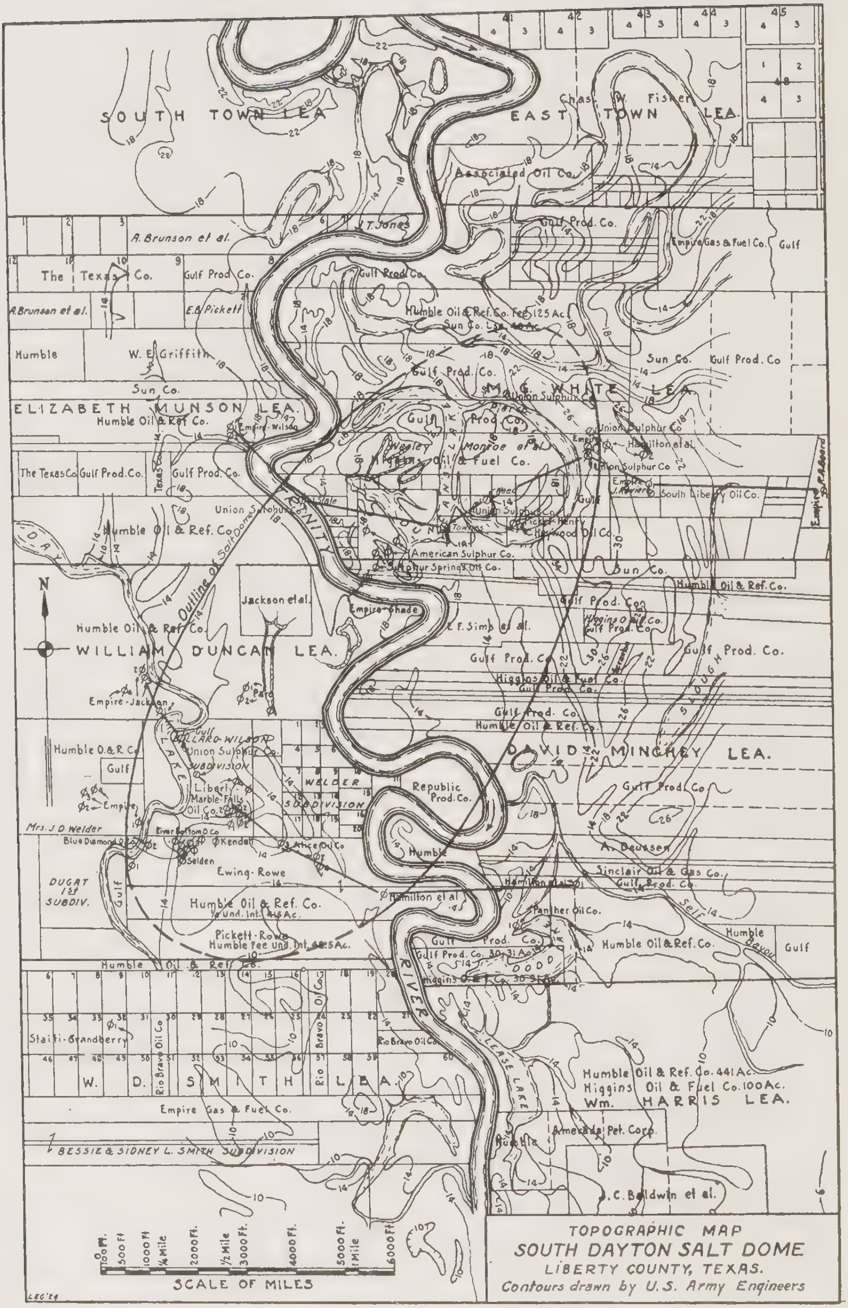

FIG. 1.—Topographic map of the South Dayton salt dome

wells there are some fine, loose, orange-colored sands which are believed to belong in the Beaumont clays, but may possibly belong to uplifted Lafayette. In the wells on top of the dome, sands and gravel are encountered down to the cap rock. For this reason, the formations directly over the dome have been assigned to the Lafayette with the Beaumont clays lapping upon the east side.

In the wells which have been drilled on the flanks of the dome the respective contacts between the different formations are not distinct, but they have been placed as shown in the cross-sections. In the Empire Gas and Fuel Company's Beard well (Fig. 2), which is believed to be far enough off the dome so that the formations are little disturbed, the Beaumont clays are about 400 feet, the Lafayette about 1,100 feet, and the Miocene about 1,900 feet thick. These classifications have been made entirely on the well log as reported by the driller.

There is a striking similarity between this section and that which is exposed at the surface along Brazos River from Hidalgo Bluff in Washington County southward to below Hempstead. Mr. William Kennedy has divided the Brazos River section into the Lagarto, Lapara, and Oakville, which are the South Texas subdivisions of the Miocene. Because of this similarity these terms have been inserted on the cross-sections although these subdivisions are usually grouped as the Fleming clay east of Brazos River.

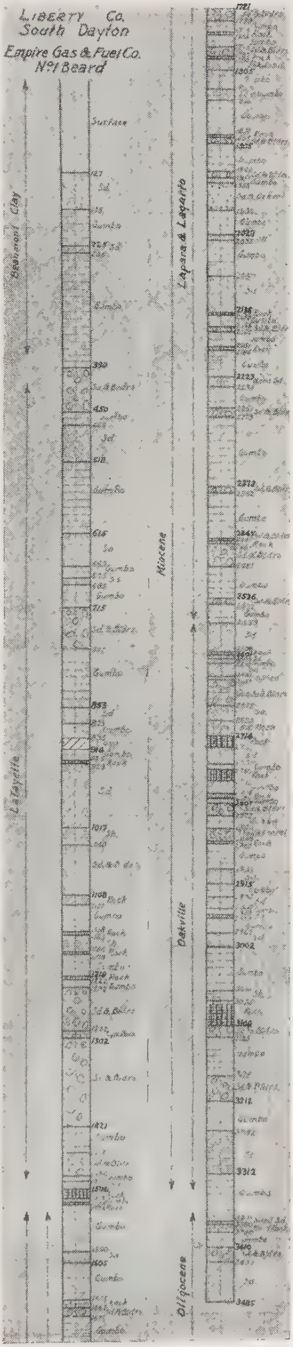

FIG. 2.—Cross-section of well of Empire Gas and Fuel Co. No. 1 Beard.

In the Beard well the Beaumont clays are inferred to include the clays and fine sands that are encountered at the surface down to 390 feet. In the Lafayette is included the material encountered between 390 and 1,500 feet, composed mostly of sand and gravel and a little clay. Gravel is believed to be characteristic of the Lafayette. Between 1,500 and 2,560 feet there is a marked reduction in the proportion of the sand and gravel to the shales, gumbos, and clays. The gumbos and shales compose about two-thirds to three-fourths of this section, whereas in the overlying Lafayette the sands compose about two-thirds to three-fourths the section. The section from 1,500 to 2,560 feet is believed to correspond to Kennedy's Lagarto-Lapara exposed in the vicinity south of Chapel Hill in Washington County and along Brazos River from the H.&T.C. Railroad bridge south to a point below the wagon bridge on the Hempstead-Bellville road. In the section from 2,560 to 3,212 feet there is again an increase in the amount of sands and gravel in the section. The driller reports oyster and other sea shells. This portion of the log is believed to correspond to the Oakville as it is exposed in Hidalgo Bluff and north of Brenham in Washington County. Between 3,212 and 3,375 feet are shales which may be either Oakville (Fleming) or Oligocene since there is shale in both the base of the Oakville and the top of the Oligocene. Below 3,375 feet sands again increase in amount. The break at 3,375 feet corresponds with a change in the J. Reviere well at 2,900 feet which the paleontologists report to be the top of the Oligocene.

The only well around this dome from which samples have been obtained for microscopic examination is that of the South Liberty Oil Company. This well, which is located about 50 feet south of the Empire's J. Reviere well, is now less than 3,300 feet deep. Paleontologists who have examined the samples are agreed that the material between 1,150 and 2,900 feet is typical Miocene. Miss Ellisor, of the Humble Oil and Refining Company, who has examined samples from 2,986, 3,001, and 3,146 feet, reports re-worked or worn Oligocene and Cretaceous Foraminifera at 2,986 and 3,001 feet, and typical Middle Oligocene Foraminifera at 3,146, suggesting transition beds at 2,986 and 3,001 feet. Miss Lane, of Mr. Alexander Duessen's office, and Miss Ellisor, who have examined samples between 3,237 and 3,257 feet, report material of Jackson age.

STRUCTURE

The subsurface geology can best be understood by reference to the accompanying maps and cross-sections. The dome has been outlined as shown. It is elliptical in shape with its axis extending

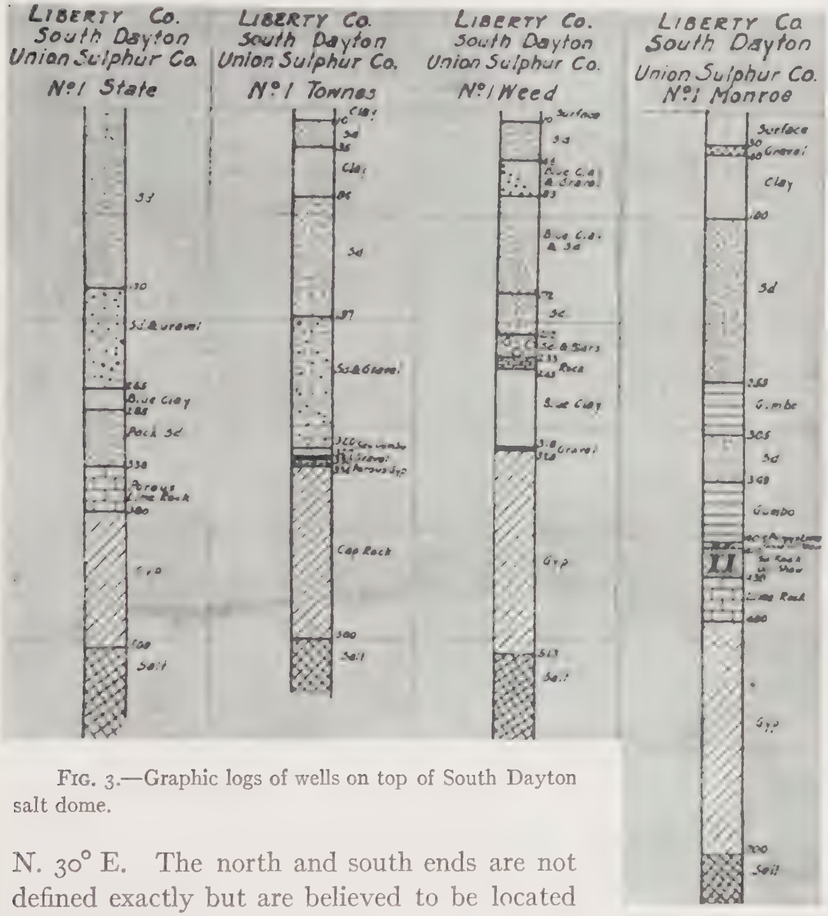

FIG. 3.—Graphic logs of wells on top of South Dayton salt dome.

N. 30° E. The north and south ends are not defined exactly but are believed to be located about as shown.

The salt core is nearly flat on top; it is highest at center and dips gently toward the edges; the east slope is steeper than the west. The sides of the salt core are very steep, but there are no wells yet drilled which indicate the exact slope at any place. The wells drilled either have encountered the cap rock and salt at shallow depths or have failed to encounter dome material at all. There is a possible exception to this in the Empire No. 4 Welder which may have encountered dome material at a depth of 2,062 feet.

Across the north end of the dome the cap is encountered at depths between 320 and 440 feet, and it ranges from 170 to 262 feet in thickness. Near the center of the dome the cap is composed entirely of gypsum while toward the edges limestone with a thickness of as much as 40 feet comes in on top the gypsum. The gypsum is thickest near the eastern edge of the cap-rock area. The cross-section *A–A* (Fig. 4) is drawn to scale, and the data composing it are believed to be accurate. The conditions across the south end of the dome are shown in cross-section *B–B* (Fig. 5). In this section the cap rock is much thinner than farther north.

If the normal dip and thicknesses of the outcropping beds be considered, the Lafayette would be expected at about 480 feet beneath the surface at

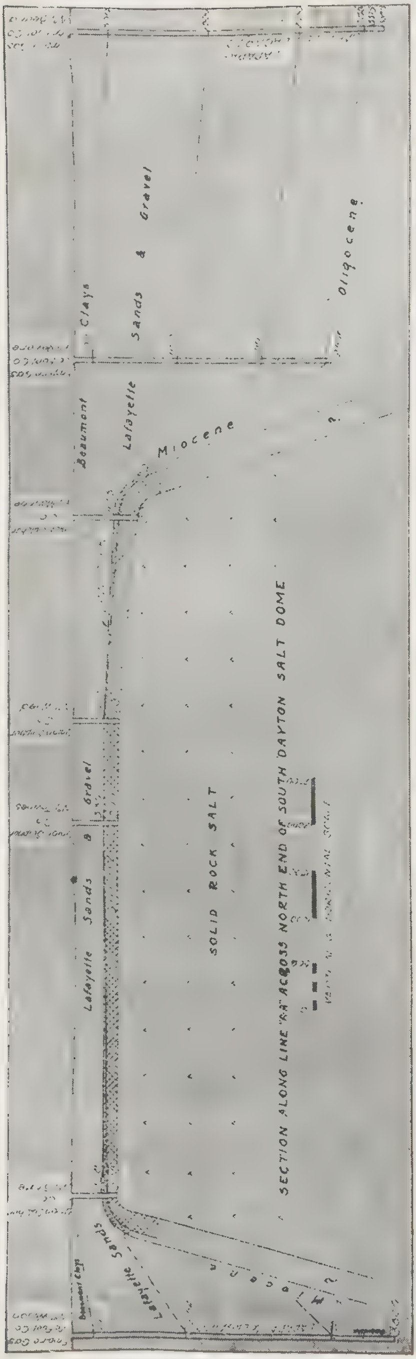

FIG. 4.—Section across north end of salt core

South Dayton, the Miocene at about 1,850, and the Oligocene at about 3,300 feet. According to our lithologic determination of the formations in the Empire Gas and Fuel Company's Beard well, which is far enough from the dome not to have been affected by any great uplift, the Lafayette was encountered at 390 feet, the Miocene at 1,500 feet, and the Oligocene at 3,375 feet. As compared with the Beard well, the Reviere wells show an uplift of at least 500 feet on the top of the Oligocene, 350 feet on the Miocene, and about 200 feet on the top of the Lafayette. The highest recognized Oligocene in the Riviere well is Middle Oligocene. If Upper Oligocene is present in the Beard well, then the Oligocene uplifted must exceed 500 feet. The lesser uplift shown by the upper formations is probably due to the thinning of the formations near the dome and to the bottom of the well being closer to the dome than the top.

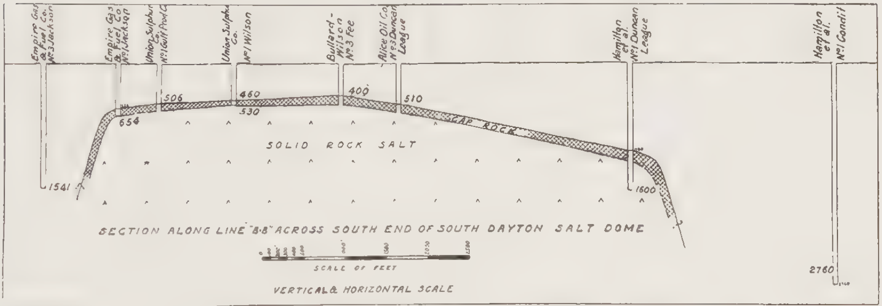
Empire Gas & Fuel Co. No. 3 Jackson
Empire Gas & Fuel Co. No. 1 Jackson
Union Sulphur Co. No. 1 Gulf Prod. Co.
Union Sulphur Co. No. 1 Wilson
Bullard-Wilson No. 3 Fee
Alice Oil Co. No. 3 Duncan League
Hamilton et al. No. 1 Duncan League
Hamilton et al. No. 1 Condit
506
460
530
400
510
654
1541
1600
2760
CAP ROCK
SOLID ROCK SALT
SECTION ALONG LINE "B-B" ACROSS SOUTH END OF SOUTH DAYTON SALT DOME
SCALE OF FEET
VERTICAL & HORIZONTAL SCALE

FIG. 5.—Northwest-southeast section across the south end of the dome

ORIGIN AND AGE OF THE DOME

The origin of the dome may be associated with lines of weakness, which developed from the same forces that caused the Balcones and Mexia-Powell lines. The direction of the major axis of the dome, which is N. 30° E., seems to be the general direction of the major axis of several of the domes, Stratton Ridge, Saratoga, and others, and is approximately parallel with the Mexia-Powell line of faulting. Stratton Ridge, Goose Creek, Barbers Hill, South Dayton, and Batson can be placed on a line with the same general strike.

The age of the dome is perhaps the same as that of the Balcones and Mexia–Powell lines of faulting, that is, Eocene or later. Around the dome the Oligocene, Miocene, and Pliocene have been uplifted. There seems to have been a period of erosion at the beginning of Lafayette times which removed from above the dome the formations which were laid down prior to the Lafayette. After the Lafayette was laid down, the movement continued and elevated the Lafayette some 400 or 500 feet above its normal position.

FUTURE PRODUCTION

This dome has been fairly thoroughly tested for oil in sands above the dome and in the cap rock. Good showings have been reported from both, but it is not likely that commercial oil will ever be developed in either.

For deep oil the dome has been tested only in three localities. The Empire Gas and Fuel Company and the South Liberty Oil Company wells on the J. Reviere land off the northeast edge of the salt dome were each good tests. The Empire Gas and Fuel Company well went to 2,896 feet. A show of light oil in a sand near the bottom threw oil over the top of the derrick, but there was apparently no great quantity of oil. The South Liberty Oil Company well, which is near the Empire well, encountered showings at about the same depth. This test, which is well located with respect to the dome, is now drilling at 3,260 feet in beds of Jackson age showing oil.

The Empire Gas and Fuel Company Wilson wells on the northwest side and the same company Welder wells on the southwest edge of the dome were probably fair tests of the Miocene and possibly of the Upper Oligocene. Good showings were reported in each of these formations, but production was not developed. In the Empire Gas and Fuel Company's Jackson wells near the center of the west side a small producer was obtained, but the wells were less than 1,550 feet deep. With the foregoing exceptions the potential possibilities of the lateral sands are untested.

NOTE

Since writing the foregoing paper, the South Dayton dome has become productive of oil. The producing area is located off the northeast flank of the dome and is known as the South Liberty field. The discovery well, known as the Winfree Trustee well on the E. W. Pickett land, is located a little more than

500 feet southeast of the South Liberty Oil Company well on the J. Reviere land, which was drilling at the time of the writing of the foregoing paper.

The discovery well came in December 31, 1924, for an initial production of 500 barrels pipe-line oil. The oil is of the standard Gulf Coast grade, ranging about 22° Baumé gravity. Development has spread principally to the south and slightly to the north from the discovery well. Its trend is in a line parallel with the edge of the dome as outlined in the paper, and at a distance of about 2,000–2,500 feet from it.

The initial production of the wells range from 500 to 4,000 barrels each. The producing formation is about 100 feet thick, ranging about 3,400–3,600 feet in depth. The productive formation is a fine-grained quartz sand of Oligocene age. There is apparently a shear zone in the immediate vicinity of the dome where the Eocene formations have been pushed up. Wells drilled in this zone are small producers of 10–20 barrels per day of about 38° Baumé gravity oil.

HOCKLEY SALT DOME, HARRIS COUNTY, TEXAS

ALEXANDER DEUSSEN AND LAURA LEE LANE

ABSTRACT

The Hockley salt dome in Harris County, Texas, is among the largest of the known salt domes of the Gulf Coast region. During the twenty-two years which have elapsed since it was discovered, nearly fifty wells have been drilled on and around it to depths ranging from 200 to 4,600 feet. Although numerous shows of oil, gas, and sulphur have been obtained from this exploration, there is today no commercial production of oil or sulphur from Hockley.

The authors point out that large areas of the cap rock are still untested and may possibly yield sulphur commercially in the future. While there is no prospect of commercial petroleum from the cap rock, there are large off-side areas which remain undrilled and offer some promise.

INTRODUCTION

LOCATION

Hockley salt dome is located in the northwestern portion of Harris County, Texas, 31 miles from Houston. The nearest railway station is the town of Hockley, on the main line of the Houston & Texas Central Railroad, 4¾ miles to the north. Katy, on the main line of the Missouri, Kansas & Texas Railroad, is 11 miles south of the dome.

The Hockley salt dome lies in the area where oil-producing domes predominate. It is situated, however, along the interior margin of this belt of productive domes, and at a greater distance from the coast (about 70 miles) than any other dome in this belt. Geologically, however, its position is no farther inland than the Humble or Davis Hill domes.

HISTORY

Attention was first directed to the indications which mark Hockley salt dome in 1905, four years after the discovery of Spindletop. To one Patillo Higgins credit for first recognition of these indications appears due. However, Lee, Napier, and Spears drilled in 1902 on the Theodore A. Sully Survey, entering a hard rock (probably sandstone) at 13 feet, and continuing in this to a depth of 60 feet. A small quantity of oil was found in the rock and a black shale was penetrated below the rock. Unlike most of the salt domes that, on the basis of topography, were recognized very shortly after the discovery of Spindletop, among them, Big Hill (Jefferson County), High Island, Barbers Hill, Damon Mound, West Columbia, Hoskins Mound, Bryan Heights, and Big Hill (Matagorda County), all of which are characterized by a pronounced local elevation at the surface, Hockley dome is not marked by a definite mound of this character. This probably accounts for the fact that it was not until four years after the finding of Spindletop that the rather prominent surface indications at Hockley were noticed.

Patillo Higgins had drilled at Spindletop before Lucas started operations there. After the Spindletop discovery he was the first to recognize the indications at Barbers Hill, High Island, the present Orange field, and a number of other domes. Visiting the Warren ranch in Harris County, Higgins realized the significance of surface indications of the Hockley dome and immediately negotiated a lease. In 1906 he began drilling operations, the first well being drilled to a depth of 730 feet, where cap rock was encountered, proving definitely the dome nature of this locality. Explorations were continued by Higgins during the years 1906, 1907, and 1908, when six wells were drilled, all of them encountering cap rock at a rather shallow depth. At that time dome development was confined to cap-rock exploration, because of the fact that the oil at Spindletop had been found in cap rock in the top of this dome. No thought was given to the possibility that oil might be present in lateral sands around the dome. All of the Higgins wells were therefore drilled within the cap-rock area, and while the first well encountered a small quantity of oil in some of the upper sands, no oil in commercial quantity was found during the period of the Higgins explorations.

Excepting one or two additional wells drilled to the cap rock, Hockley received no further attention until the year 1916, following the important discovery made at Sour Lake and Humble, in 1913, that oil in large volume existed not only in the cap rock, but likewise at deeper levels in lateral sands surrounding the domes. The Sour Lake and Humble development immediately focused attention again upon the considerable number of domes which had failed to yield production in the cap rock, and a new era of salt dome exploration was inaugurated.

In line with this development, the Texas Company, in 1916, acquired a new lease at Hockley, and in that year drilled a well to a depth of 3,100 feet. This well encountered cap rock at 114 feet, and drilled into rock salt at 1,109 feet. The salt was said to be unusually pure, and was used by the drillers for table salt in camp. Due to a controversy concerning its leasehold rights, the Texas Company abandoned operations with the completion of this test, and the Gulf Production Company then secured a lease on the Coghill and Gulliver surveys, and began a period of very active exploration.

The Gulf Production Company's No. 1 Warren was completed in February, 1917, at a depth of 397 feet. This well was drilled into the cap rock and was very quickly abandoned. The drilling campaign of the Gulf Production Company extended from 1917 to 1922, inclusive, in which interval nineteen wells were drilled. None of these succeeded in establishing commercial production. All but five of the wells were drilled on the cap rock, and did very little except to define the limits of the dome. They were valueless as tests for oil.

In 1919 the Texas Exploration Company acquired leases on the west, northwest, and northeast sides of the Hockley dome, including practically all of the dome not covered by the Gulf Production Company's lease. The Texas Exploration Company has conducted a very active campaign of drilling since it began its first well in 1919, and this campaign is still in progress. In the five years that the company has been at work it has drilled a total of nineteen wells, and is now drilling its well No. 20. Of all these wells, however, only six have been off-side wells. The remainder have been drilled on the cap rock, in the effort either to establish some cap-rock production or to define the limits of this rock.

The fifth off-side test (Texas Exploration Company's No. 13 Warren) succeeded in finding an oil sand at 1,750 to 1,820 feet, and a small well with initial production of 25 barrels of 28-gravity oil was made in this sand.

The Texas Exploration Company's well No. 15, located 250 feet northeast of No. 13, was drilled to a depth of 2,090 feet, and was completed in February, 1924. It encountered the same oil sand as that found in No. 13, at a depth of 2,052 to 2,090 feet, and a 75-barrel well with oil of 22 gravity was completed in this sand.

Well No. 17 was drilled into anhydrite at 3,039 feet. It encountered highly saturated oil sands between 2,941 and 2,976 feet, but for some reason it was not an oil well.

In the entire twenty-two years of exploration at Hockley there have been drilled a total of forty-six wells, with one well drilling at the present time. Of these, thirty-two wells were either on the cap rock or were very shallow tests, less than 400 to 500 feet in depth. The remaining fourteen wells were off-side tests to depths ranging from 1,750 to 4,412 feet, and of these, two have succeeded in establishing a small quantity of production. It is worthy of note that there is still a very considerable part of the circumference of the dome untested, and in the untested portion there is still a possibility of producing oil. As indicated on the map (Fig. 5), the deep drilling has been confined to four spots around the periphery of the dome. These spots include the tests made by the Gulf Production Company in wells No. 12 and No. 13, on the southeast side of the dome; the group of four wells of the Texas Exploration Company on the Houston Tap & Brazoria Railroad Company Survey No. 1, on the southwest side of the dome: the group of wells represented by Texas Exploration Company's wells No. 13, No. 15, and No. 17, on the northeast side of the dome; and the tests of the Gulf Production Company represented by wells No. 3, No. 6, and No. 15, on the east side of the dome.

All of the lateral area extending from Texas Exploration Company's well No. 10, on the southwest side, to its well No. 17, on the northeast side, representing fully one-half of the periphery, is still untested. There is likewise a gap of more than a mile between Texas Exploration Company's well No. 4 and Gulf Production Company's well No. 12. Likewise there is another gap on the southeast side of the dome, of more than a mile, between Gulf Production Company's well No. 13 and the same Company's well No. 3, still untested.

PHYSIOGRAPHY

Hockley salt dome is located at the interior margin of a seaward-facing terrace of the coastal plain of Texas, which the senior author has described in a recent paper[1] as the Alice Terrace. The outer and inner margins of this terrace are seaward-facing scarps, and the terrace is coterminous with the outcrop of the Lissie formation.

This terrace lies at a considerably higher elevation than the one immediately adjoining it to the south (described by the senior author as the Beaumont Terrace), and at a slightly less elevation than the terrace which lies immediately adjoining it to the north (Realitos Terrace).[2]

In Harris County the Alice Terrace is a very flat plain with dissection confined to the margins of the drainage channels. The soils of this terrace are mainly sand or sandy loams, and a considerable portion of this plain in Harris County is set with pine timber.

The scarp, which marks the interior margin of this terrace, is the most pronounced topographic feature in Harris County. It is plainly discernible to the eye, and can be traced by a line of low hills extending across the county in an east-west direction and passing into Montgomery County, about five miles north of Humble. It is very clearly defined on the topographic map, with one-foot contours, of Harris County, published by the U. S. Geol. Survey.

At the base of this scarp, in the vicinity of Hockley, the elevations average 170 feet. The high points on the crest of this scarp reach elevations as high as 200 feet, and an average height for this scarp of 30 feet above the lower plain may be safely assumed.

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[1] Alexander Deussen, "Geology of Coastal Plain of Texas, West of Brazos River," *U. S. Geol. Survey Professional Paper 126* (1924), pp. 4–5.

[2] *Ibid.*

Hockley salt dome lies on this carp, its southeastern flank lying well within the limits of the Alice Terrace, and its northwestern flank extending across the scarp to the edge of the Realitos Terrace.

Because of its peculiar position with respect to this scarp, Hockley salt dome presents unusual topographic characteristics. Unlike many of the other domes, which are marked by distinct topographic mounds, Hockley dome is not characterized by a distinct surface mound, and it is only by a critical study of the topographic map that the influence of this salt intrusion can be recognized in the contours. A topographic map of the area in which Hockley dome is located is shown in Figure 1. An inspection of this map will show the influence of this intrusion in the local topography.

If the 170-foot contour be taken as typical, its normal course, when uninfluenced by the salt-dome intrusion, would be in a northeast and southwest direction, and it would normally extend directly across the Houston Tap & Brazoria Railroad Company Survey, from its northeast corner to its southwest corner. It will be noted, however, that instead of following this course, which is parallel to the present Gulf coast, at the northeast corner of the Houston Tap & Brazoria Railroad Company Survey this contour makes a sharp turn to the southeast, where it loops around a high area at the southeast corner of this survey. It then turns northwestward again near the center of the north line of this survey before resuming its normal course. There is an outlier of the 175-foot contour at the southeast corner of this survey, and this area of surface uplift is coincident with the southwestern margin of the dome. This is the only topographic influence discernible in connection with this salt-dome intrusion.

The disturbance of normal topography is evidently subsequent to the deposition of the Lissie formation, which underlies the Alice Terrace. Other well-known mounds of the Coastal Plain, such as Spindletop, Barbers Hill, Damon Mound, and Big Hill (Jefferson County), are without question of post-Beaumont age and it is reasonable to assume that the Hockley disturbance is of about the same age, which would indicate that the movements at Hockley had continued well into the late Pleistocene.

The area above the salt core itself at Hockley is marked by a rather peculiar characteristic local topography. There are numerous pronounced small elevations, which have been described as pimples, and which occur at a number of places on the Coastal Plain. The surface of the land is locally very irregular and very rough. There are numerous depressions between these small elevations, and at a number of places vegetation does not grow, due to the presence of alkali and a small amount of salt in the soil. Near the southeast corner of the Houston Tap & Brazoria Railroad Company Survey, and at the point previously described as the one where the disturbance of the normal surface topography can be detected, there are, during periods of wet weather, gas seepages, and a post-hole auger in this area will uncover a small quantity of gas. In fact when Mr. Higgins first found this locality, he demonstrated the presence of gas in this vicinity by digging post holes and then igniting the gas. Likewise, in the soil in this immediate vicinity small flakes of sulphur can be detected, these being associated with the gas. Strong sulphur water which will blacken a coin in a few minutes and will leave a very large residue of mineral matter is present in the shallow wells, and is likewise a very characteristic feature in connection with the surface phenomena at Hockley dome.

SURFACE GEOLOGY

Actual exposures of the formations at Hockley are very scarce. At the northeastern margin of the dome, and near the southeast corner of the Robert Hall Survey, outcrops of red sand, which unquestionably can be referred to the Lafayette formation, are to be observed.

In the banks of Rock Hollow, which cuts across the Thomas Coghill Survey, extending south from the Warren ranchhouse and draining into Big Cypress Creek, are outcrops of a gray sandstone which can probably be referred to the Miocene or Lower Pliocene, and correlated with the Fleming. It would appear from this evidence that the formation above the cap rock at Hockley is the lower

Fleming. The junior author has made a microscopic examination of this material, and finds that it is indurated sulphurous yellow sandy clay. When washed, the material leaves fragments of the clay and a small amount of blue sand. A sample from a nearby outcrop showed gray hard sandstone with a lime matrix. The material when washed

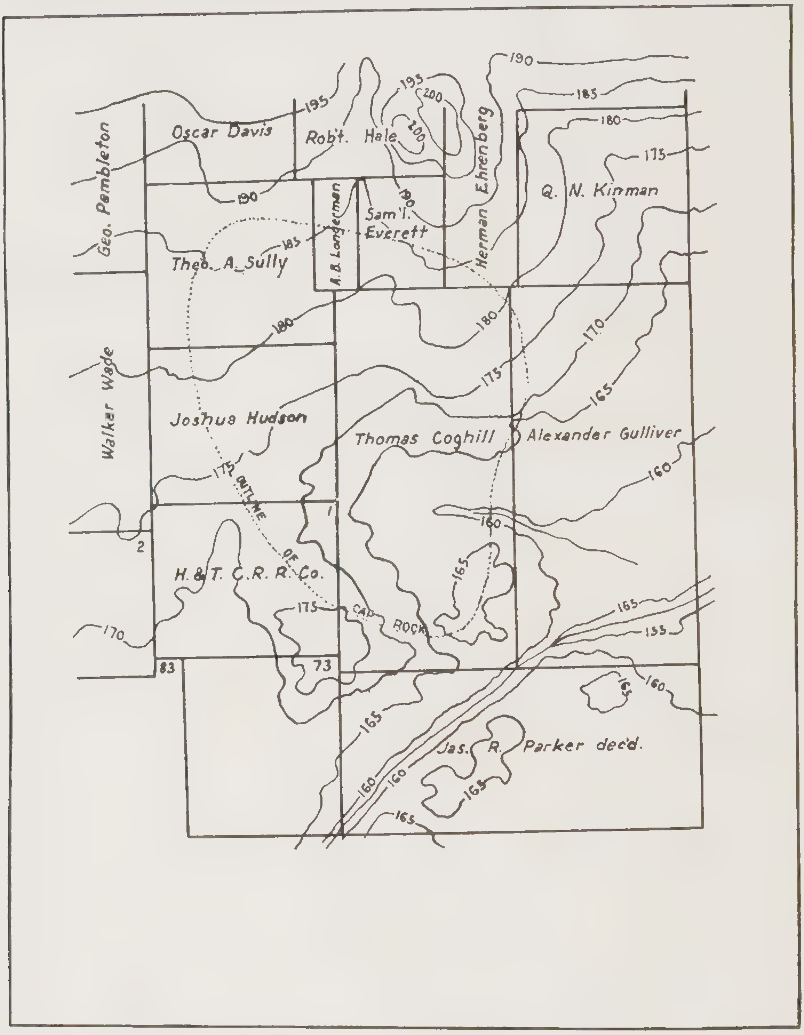

FIG. 1.—Map showing topography of Hockley Salt Dome in Harris County, Texas.

leaves fragments of the sandstone incrusted with clay and lime particles, and a residue of moderately coarse sand which constitutes 40 per cent, approximately, of the washed material.

Shark teeth, found in a bed of shale at 300 feet in Higgins well No. 1, were examined by Dr. L. Hussakof, of the American Museum of Natural History, New York, who reports:

> The shark teeth are identical with, or very close to, *Oxyrhina minuta* Agassiz, a Lower Miocene (Europe), and Upper Eocene (North Carolina) species. The other teeth represent the teleoston genus *Sphyraena*, which ranges from Eocene to modern times.

As it is highly improbable that Eocene beds were entered at a depth of 300 feet in this well, a Miocene (Fleming) horizon is indicated.[1]

The appearance of Fleming above the cap rock is distinct geologic evidence of uplift. This formation must have been intruded completely through the Lafayette, which in this vicinity is normally about 800 feet in thickness.

In the off-side wells immediately surrounding the area of the cap rock, the Lafayette is the surface formation, and is penetrated in the upper portion of these wells.

No dips in these surface formations can be detected which can be used to outline the limits of this dome.

SUBSURFACE GEOLOGY

Introduction.—A contour map showing the subsurface structure of Hockley salt dome is presented in Figure 2, and sections across the dome in Figures 3 and 4. These give an accurate picture of the geology of this dome.

It will be noted from the sections and map that Hockley is a typical Gulf Coast salt-dome structure. There is an intruded plug of rock salt capped by a typical cap rock composed of a sheet of anhydrite and an overlying sheet of limestone with the adjacent formations tilted against the sides. The outline of the dome is oval or egg-shaped, with the major axis trending in a direction N. 22° W., and the minor axis trending approximately N. 38° E.

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[1] Alexander Deussen, "Geology and Underground Waters of the Southeastern Part of the Texas Coastal Plain," *U. S. Geol. Survey Water Supply Paper 335* (1914), p. 76.

Salt core.—The salt core at Hockley rises to within 1,000 feet of the surface, and so far as our information extends, the top of the salt plug is fairly flat, as is shown on the cross-sections. The diameter of the core at the top of the salt from southwest to northeast, along section AA, is approximately 4 miles, or 21,000 feet, which is a distance considerably in excess of the average dome of the Gulf Coast.

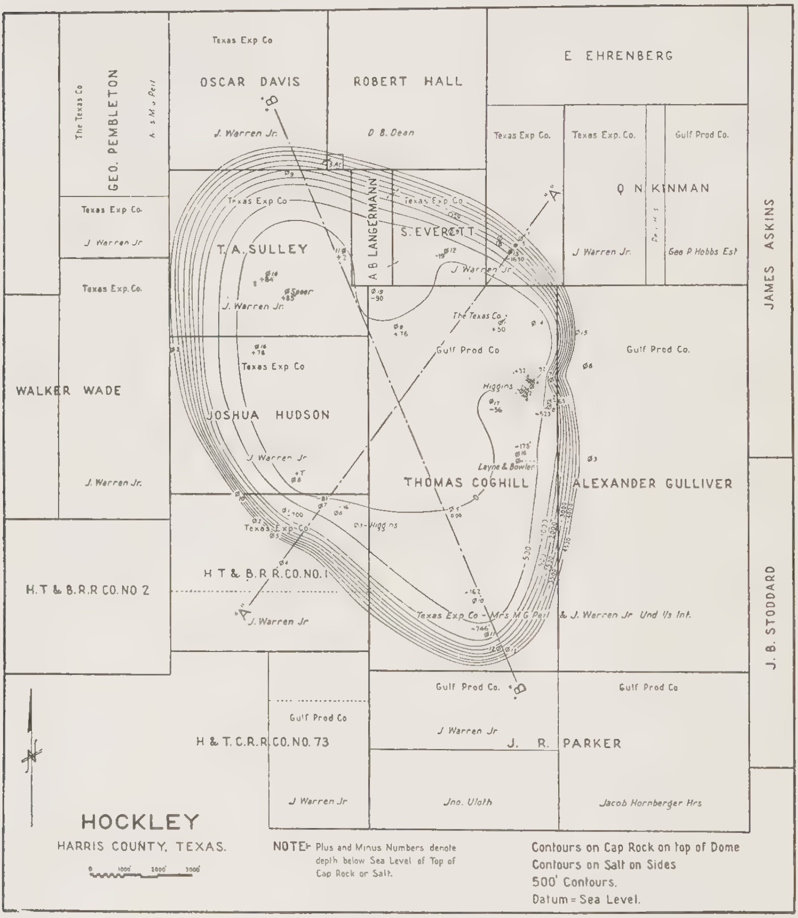

FIG. 2.—Subsurface contour of Hockley Salt Dome

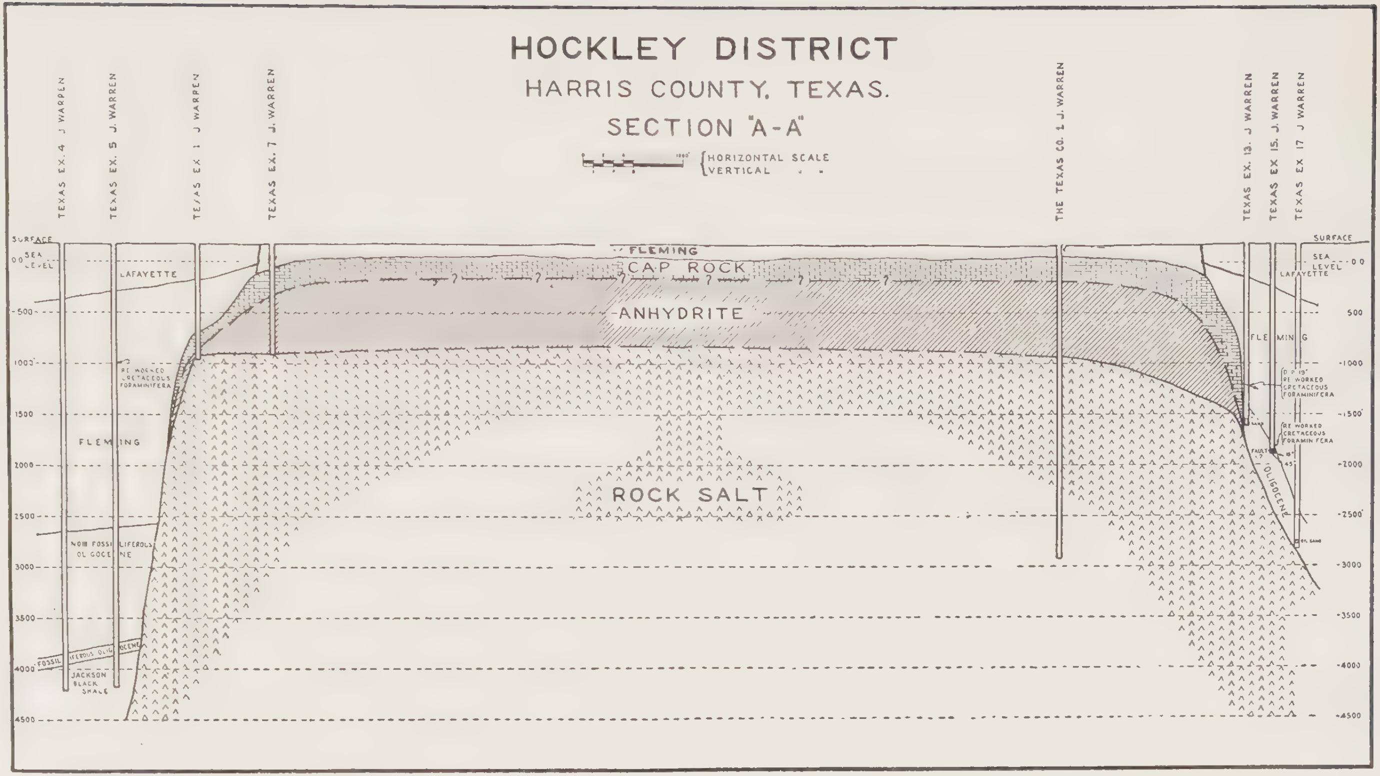

FIG. 3.—Section across Hockley Dome

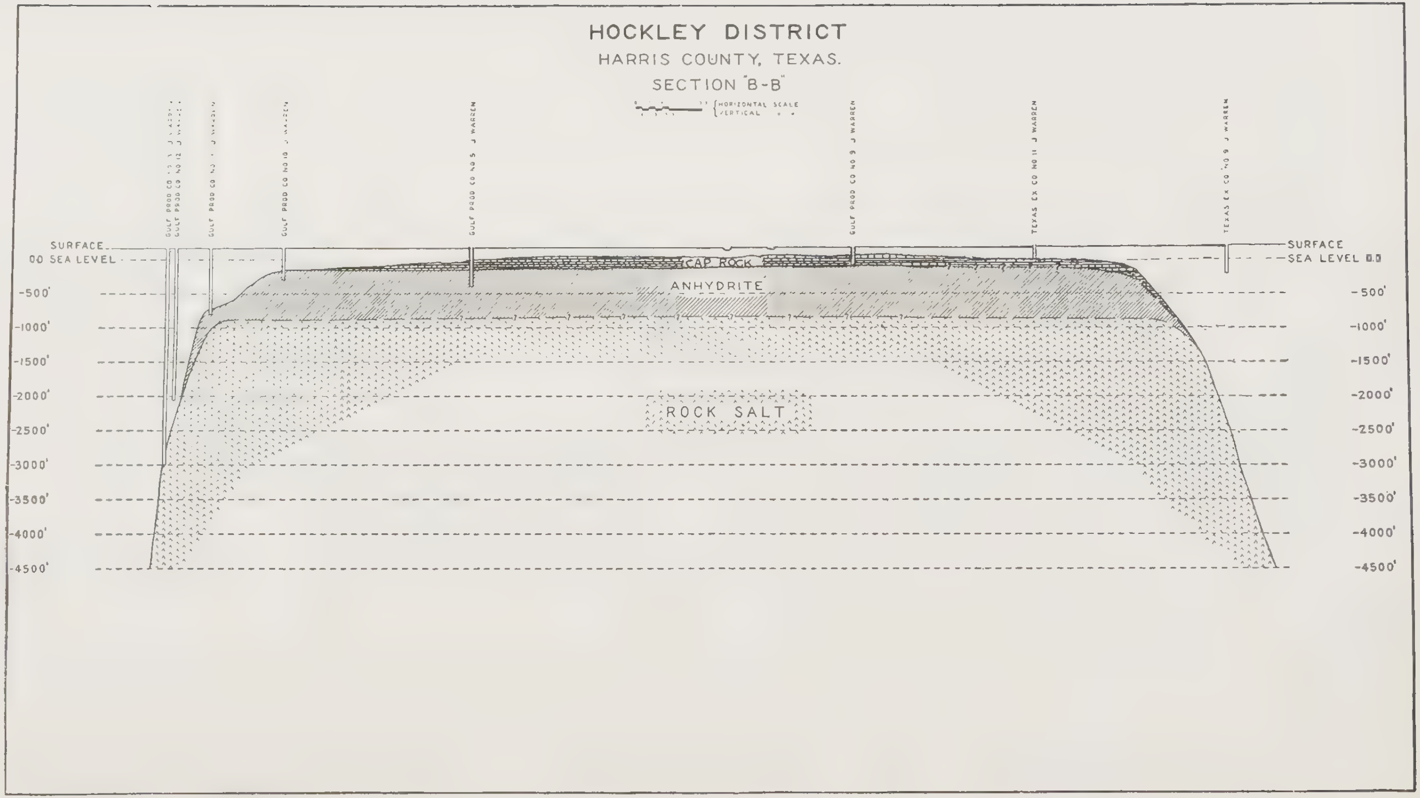

FIG. 4.—Section across Hockley Dome

The diameter of the salt plug in this same section at the 4,000-foot contour is approximately 4¼ miles, or 23,000 feet.

Along section BB, which extends from southeast to northwest, and in line with the major axis of this dome, the diameter of the salt core at the top and near the 1,000-foot contour is approximately 28,000 feet, or about 5.3 miles, which is also very considerably in excess of the diameter of the average dome. Only the Humble and Stratton Ridge domes approximate these dimensions. At the 4,000-foot contour in this section this dome is approximately 33,000 feet in width, or very nearly 6.2 miles.

So far as this structure has been explored, the sides of the salt core have very steep dips, the slope on the southeast side being approximately 2,500 feet in a horizontal distance of 1,750 feet, or at an angle of 55°. On the southwest side the salt surface dips approximately 3,500 feet in a horizontal distance of 1,500 feet, or at an angle of 67°. On the northeast side the dip of the salt surface is 2,000 feet in a horizontal distance of 1,000 feet, or at an angle of 60°. There is no information available as to the dip of the salt surface on the north or northwest flanks of this dome, as no wells have been drilled on these sides to date.

Cap.—The salt core at Hockley is overlain by a typical cap such as is found on most of the domes in the Gulf Coast district. This cap is composed of a sheet of porous cavernous limestone saturated with small quantities of oil and variable quantities of sulphur in places. The limestone sheet is approximately 450 feet in thickness over the greater part of the salt core.

Beneath the limestone sheet occurs a thick bed of dense, finely crystalline anhydrite, lying directly on the salt. This anhydrite is approximately 1,500 feet in thickness.

The cap forms a thimble over the salt, feathering out toward the edges, and extending down the sides of the salt core for a limited distance as a thin wedge of material. It is probable that in the lower limits of the dome there is no typical limestone cap between the salt and the normal sedimentary formations.

The contour of the top of the limestone cap rock is shown on the map (Fig. 5) by means of 50-foot contours. The highest contour passes near the northeast corner of the Houston Tap & Brazoria

Railroad Company Survey No. 1, the northeast corner of the Thomas Coghill Survey, and near the center of the T. A. Sulley Survey. The highest point on the cap rock, so far as known, occurs in the Spear well on the T. A. Sulley Survey, in the northwestern portion of the dome, where the top of the cap rock lies 85 feet above sea-level, or only 100 feet below the surface.

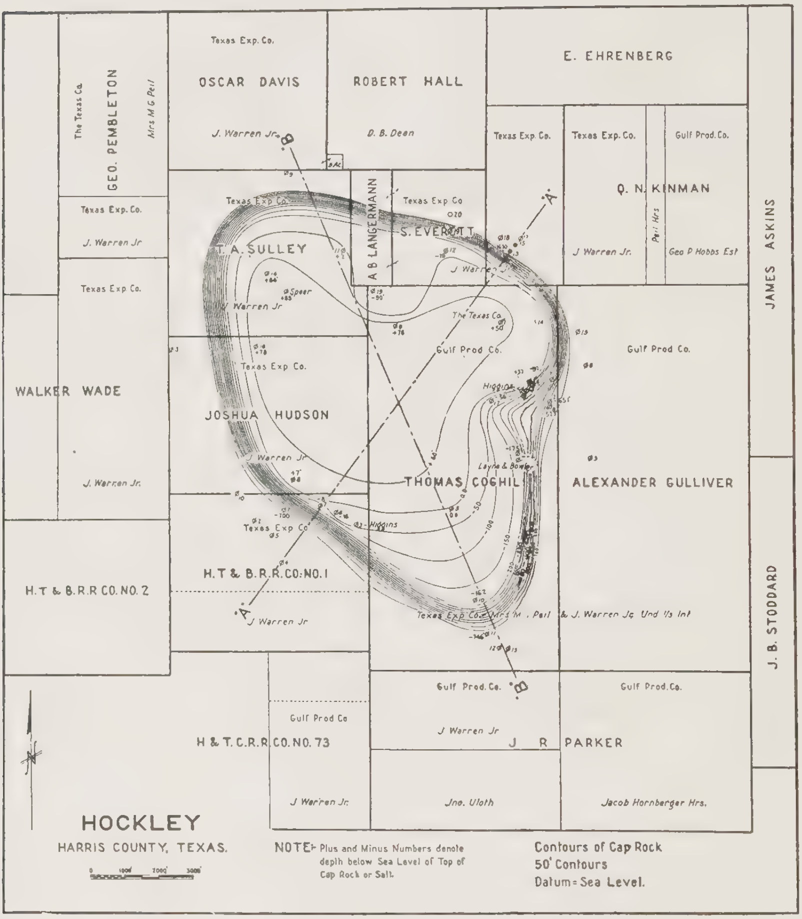

FIG. 5.—Map showing contour of the cap rock at Hockley

The sea-level contour includes the greater portion of the area of the cap rock. The 200-foot contour marks approximately the outer limit of the cap rock, where it begins to dip steeply over the sides of the salt. Between the 200- and the 700-foot contours, the surface of the cap rock has a very steep dip, and if the overlying material were removed from this dome, these sides of the cap rock would appear as almost vertical cliffs 500 feet in height.

STRUCTURE OF SURROUNDING SEDIMENTS

Section AA gives a very good picture of the structure of the adjacent sediments. On the southwest side of the structure it appears, from the information available on the basis of drilled wells, that the formations are not very greatly tilted against the sides of the dome. It seems that the plug has cut through the formations at this point without dragging them very far vertically upward. The dip of the Oligocene on this side is approximately 500 feet in a horizontal distance of 2,000 feet, or at an angle of 10°. The Fleming and Lafayette formations appear to have about the same dip. On this side of the dome, what is hereafter called the non-fossiliferous Oligocene makes its appearance in well No. 5 of the Texas Exploration Company on the Warren lease, at approximately 2,625 feet below sea-level, and the fossiliferous Oligocene in this same well makes its appearance at approximately 3,750 feet below sea-level.

On the northeast side of the dome, as disclosed in wells No. 13, 15, and 17 of the Texas Exploration Company on the Warren lease, the dip of the adjacent formations seems to be considerably greater than is the case on the southwest side, and it is worth noting that in this particular area a small quantity of production has been found. On this side the top of the Fleming formation seems to have a dip of approximately 20°, and the top of the non-fossiliferous Oligocene has a dip of approximately 65°.

It appears that on this side of the dome the top of the non-fossiliferous Oligocene, as indicated in well No. 13 of the Texas Exploration Company, lies at a depth of approximately 1,400 feet below sea-level, and in well No. 17 of the Texas Exploration Company, at a depth of approximately 2,400 feet below sea-level. It is interesting to note that the top of the non-fossiliferous Oligocene makes its appearance on this side of the dome very nearly 1,000 feet higher than on the southwest side, and it is likewise interesting to note that on this section of the dome, where the Oligocene beds have been dragged up much higher than on the southwest side, some production is obtained. It is probably true that a condition prerequisite to the occurrence of oil in the Gulf Coast salt domes is that the adjacent formations should be dragged up around the sides of the salt a considerable distance above their normal position.

STRATIGRAPHY

The normal sedimentary formations of the Hockley salt dome include the following:

Age	Formation
Pleistocene	Lissie
Late Pliocene	Lafayette
Pliocene Miocene	Fleming
Oligocene	Oligocene
Eocene	Jackson

Lissie formation.—As previously mentioned, Hockley salt dome is located at the western margin of the outcrop of the Lissie formation. Owing to the uplift that has occurred in connection with this salt intrusion, there is no exposure of the Lissie in the immediate vicinity of the dome, and no materials of this formation are encountered in the wells drilled on top of this dome. Outcrops of the Lissie occur in a circumferential ring on the east, south, and southwest sides of the dome. The Lissie formation is made up of red sand and lenses of red gravelly clay. Beds of gravel are likewise very common.

In a spring in the vicinity of Gulf Production Company's wells No. 12 and No. 13, on the southeast side of the dome, there has recently been obtained an elephant tooth (third molar, upper left jaw, *Elephas imperator*) of early Pleistocene age.

Lafayette formation.—The cap-rock area at Hockley, with the exception of a thin veneer of recent material, is marked by the outcrop of an inlier of the Fleming formation. This inlier occurs, as previously indicated, at the normal contact line of the Lissie and Lafayette. Owing to the uplift of the Lafayette around the margins of this dome, a narrow loop of Lafayette material extends out from the main area of the Lafayette surrounding the inlier of Fleming, on the east, south, and west sides. Beyond this loop of Lafayette on those sides outcrops of the Lissie appear.

The Lafayette directly overlies the Fleming clay on the sides of the dome. It does not overlie the Fleming in the cap-rock area.

As recorded by the drillers' logs, this formation at Hockley consists mainly of red sand, gravel, and bowlders. Beds of red gumbo and clay are likewise present. The presence of gravel and the predominating red clay of these beds readily distinguish them from the underlying Fleming.

The accompanying chart (Fig. 6) of the diagnostic characters of the strata penetrated in Texas Exploration Company's well, John Warren No. 5, will readily show the difference in the constitution of the materials as compared with those of the underlying Fleming. Charts prepared for the various wells drilled on this dome, which are not reproduced here, show the same general characteristics for this formation.

No fossils are found in the Lafayette, which definitely fixes its age, but it is generally considered to be either very late Pliocene or very early Pleistocene.

In well No. 5 of the Texas Exploration Company on the Warren lease, this formation is approximately 400 feet in thickness. In well No. 4 on this same lease it is approximately 500 feet thick, and in well No. 17 it is approximately 800 feet thick.

Fleming formation.—The Fleming formation immediately underlies the Lafayette at Hockley, and overlies the Oligocene. As will be noted from the chart (Fig. 5), the formation consists mainly of blue calcareous gumbo. In the 2,600 feet of material representing the Fleming in Texas Exploration Company's No. 5 well on the Warren lease, blue calcareous gumbo is the predominating material. This is the case in seventeen 100-foot intervals as compared with nine 100-foot intervals which are composed of different materials. Out of the nine exceptional instances, three of these units are listed as pink calcareous gumbo, instead of blue calcareous gumbo; and two units are listed as blue shale. Only four of the 100-foot intervals in the total Fleming show a predominance of sand.

Pyrite in small quantities occurs in the sands of this formation,

	Number.	Depth.	Thickness in 100 feet expressed in per cent.						Predominant.						Color.				Caprock including anhydrite.	Rock salt.	Lime.	Pyrite.	Pliocene fossils.	Miocene fossils.	Oligocene fossils.	Jackson fossils.	Glauconite
			Sand	Gumbo or Clay.	Shale.	Rock.	Gravel.	Boulders.	Sand	Gumbo or Clay.	Shale.	Rock.	Gravel.	Boulders.	Blue.	Green	Pink.	Black.									
LAFAYETTE	1	0-100	52	48			×	×		×																	
	2	100-200	37	63			×			×																	
FLEMING	3	200-300	14	86				×		×											×			×			
	4	300-400	61	39					×																		
	5	400-500	26	35	11	6	15	7		×					×												
	6	500-600		28	67			5			×				×												
	7	600-700	4	38	58			×			×				×												
	8	700-800	6	89	5			×		×					×												
	9	800-900	56	44				×	×						×						×	×		×			
	10	900-1000	12	88				×		×					×						×			×			
	11	1000-1100	49	40				11	×						×						×						
	12	1100-1200		82		18				×							×				×			×			
	13	1200-1300	17	54	15	14				×							×				×	×		×			
	14	1300-1400	42	58				×		×					×		×										
	15	1400-1500	6	88		6		×		×					×												
	16	1500-1600	8	66		26				×					×												
	17	1600-1700		73	9	18		×		×					×						×						
	18	1700-1800		44	53	3		×			×				×							×		×			
	19	1800-1900	14	53	25	8		×		×					×						×	×					
	20	1900-2000		88	12					×					×						×	×					
	21	2000-2100	33	32	35						×				×												
	22	2100-2200	43	4	22	31			×						×							×					
	23	2200-2300	10	86		4				×					×						×	×					×
	24	2300-2400		100						×					×												
	25	2400-2500		62	12	26		×		×					×						×						
	26	2500-2600		100						×					×												
	27	2600-2700		91		9				×					×												
	28	2700-2800		58		42				×					×						×	×					
OLIGOCENE	29	2800-2900		31	53	16		×			×				×						×						
	30	2900-3000		13	34	53						×			×												
	31	3000-3100		26	72	2		×			×				×							×					
	32	3100-3200		32	34	34		×			×				×						×	×					
	33	3200-3300		8	72	12		8			×				×						×						
	34	3300-3400	10	24	60	6		×			×				×						×						
	35	3400-3500		48	50	2					×				×						×						
	36	3500-3600		30	70						×				×						×	×					
	37	3600-3700		43	41	16				×					×						×	×					
	38	3700-3800		28	64	8		×			×				×						×	×					
	39	3800-3900		17	36	42		5				×			×						×	×					
	40	3900-4000		24	18	58						×			×						×	×			×		
JACKSON	41	4000-4100		29		71						×						×			×	×				×	
	42	4100-4200		28	70	2		×			×							×			×	×				×	
	43	4200-4300			100						×							×								×	
	44	4300-4360			100						×							×									

FIG. 6.—Chart of diagnostic character of strata penetrated in Texas Exploration Company well No. 5—John Warren at Hockley, Harris County, Texas, as determined from drillers log and samples.

and in the particular well previously referred to, No. 5, pyrite is recorded in eight of the 100-foot units. This pyrite is probably not indigenous to the formation, but is an accessory mineral related to dome intrusion.

There is one glauconite horizon recorded in well No. 5, in the 2,200–2,300-foot unit, and glauconite has been noted in other wells on this dome in the Fleming formation. For example, in well No. 10 of the Texas Exploration Company on the Warren lease, a glauconite horizon was encountered at 1,900 to 2,000 feet. It is also recorded at 1,400 to 1,500 feet in well No. 13 of the Texas Exploration Company on the Warren lease, in approximately the same relative stratigraphic position in the Fleming as in well No. 10. In this case, however, there are only some 1,100 feet of material represented by this formation, the lower portion of the Fleming not being present here. In well No. 15 of the Texas Exploration Company on the Warren lease, glauconite was recorded between 1,500 and 1,700 feet, which is probably the identical horizon as that in No. 13.

The Fleming formation is characterized by the presence of reworked Cretaceous Foraminifera. In the Hockley wells, these Foraminifera are confined to the Fleming formation, not being present in the overlying Lafayette or the underlying Oligocene. The species recognized in these wells include the following:

REWORKED CRETACEOUS FORAMINIFERA IN THE FLEMING FORMATION AT HOCKLEY

Trochammina inflata
Textularia sp.
Anomalina sp.
Globigerina sp.

In addition to these reworked Cretaceous fossils, the Fleming at Hockley contains fish teeth.

The maximum thickness of the Fleming recorded in the Hockley wells is 2,600 feet. This extreme thickness is exceptional, and suggests that Hockley dome is probably located near the base of some regional synclinal depression.

The Fleming formation includes materials of early Pliocene and of Miocene age, representing the equivalents of what the senior author has described as the Oakville sandstone, the Lapara sands, and the Lagarto clays in the region west of Brazos River.[1]

The formation as encountered in these wells is identical in character with the formation as shown on the outcrop farther north, in Walker and adjoining counties.

Oligocene.—Beds referred to the Oligocene are encountered in the Hockley wells below the Fleming and above the Jackson formation.

As shown in the diagnostic chart (Fig. 5), the upper 1,000 feet of this unit consists predominantly of blue calcareous shale. In this part of the formation in the Texas Exploration Company's No. 5 Warren well, blue calcareous shale is recorded in six 100-foot intervals out of the ten 100-foot intervals represented. In one case blue rock is recorded and in another case blue gumbo.

In view of these facts, blue calcareous shale may be considered to be the characteristic material of the upper 1,000 feet of the Oligocene in the Hockley wells.

Pyrite was recorded in well No. 5 in nearly every sample examined from this formation, but, as in the case of the Fleming, this mineral is probably secondary, being related to the dome intrusion.

In well No. 5 of the Texas Exploration Company the lower 300 feet is recorded as rock, which is probably hard sandstone. The same is true with respect to the lower 200 feet of well No. 4 of the Texas Exploration Company, and it may be safely considered that the lower 200 or 300 feet of the Oligocene in the vicinity of Hockley dome is blue hard sandstone which may be correlated with the Vicksburg limestone of Louisiana and Mississippi. The upper blue shale series, approximately 1,000 feet in thickness, may be considered to be the equivalent of the Middle and Upper Oligocene, as shown on the outcrop by the Catahoula sandstone and the clays which Dumble has described as the Onalaska clays.[2]

The upper blue calcareous shale portion of the Oligocene in the Hockley wells contains no fossils, at least none of the cores recovered from any of the wells have shown any fossils in this part of the formation.

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[1] Alexander Deussen, "Geology of Coastal Plain of Texas, West of Brazos River," *U. S. Geol. Survey Professional Paper 126* (1924), pp. 97–102.

[2] E. T. Dumble, "The Geology of East Texas," *University of Texas Bulletin 1869* (1918), pp. 189–218.

The lower sandstone series has yielded a megascopic fauna, notably in wells No. 4 and No. 5 of the Texas Exploration Company. This fauna consists of the following species, identified by Mrs. Paul Applin, Dr. C. W. Cooke, and Dr. Julia Gardner.

Oligocene Fossils from Wells at Hockley

Arca sp.	..........Identical with Vicksburgian sp.
Turritella sp.	
Terebra sp.	..........Similar to Vicksburgian sp.
Natica sp.	
Phos sp.	
Nassa sp.	

No microscopic fauna has been found in the Oligocene in any of the Hockley wells.

The total thickness of the Oligocene, as shown in well No. 4 of the Texas Exploration Company, is 1,700 feet, of which the lower 200 feet consists of sandstone. This may be taken as representing the maximum thickness of this formation in the vicinity of the Hockley dome.

When taken in connection with the rather excessive thickness of the Fleming in this section, it is further evidence that Hockley dome is situated in a synclinal depression.

Jackson formation.—The lowest and oldest formation penetrated in any of the wells at Hockley is the Jackson. This is reached between 4,000 and 4,380 feet in the Texas Exploration Company's No. 5 Warren well, and between 4,200 and 4,412 feet in the No. 4 well. It immediately underlies the Oligocene.

The formation as recorded in these wells consists of black shale, and this is the characteristic black shale that commonly occurs immediately on top of, or adjacent to, the salt in many of the Gulf Coast salt domes.

In the only two wells which have reached this formation at Hockley, a very good collection of both megascopic and microscopic fossils has been obtained. The species include the following:

JACKSON FOSSILS FROM WELLS AT HOCKLEY

(Identified by Mrs. Paul Applin)

FORAMINIFERA

Ammobaculites sp., cf. to *foliaceous*
Textularia hockleyii
Textularia, probably var. of *sagittula*
Bolivina sp.
Nodosaria consorbrina, var. of *emaciata*
Cristellaria orbicularis
Cristellaria aculeata
Uvigerina pigmaea
Discorbis sp.
Truncatulina sp.
Pulvinulina sp.
Nonionina scapha
Nonionina sp.
Cornuspira, cf. *foliacea*
Quinqueloculina sp.
Triloculina oblonga

LARGE FOSSILS

Adeonellopsis teanoversa (Jackson and Claiborne)
Polyascosoecia sp.
Idmidronea rosacea
Venericardia sp.
Venericardia rotunda, young—broken (Eocene)
Corbula wailesiana (Jackson)
Phos sp. (close to Jackson sp.)
Volutilithes sp.
Volutilithes, probably *petrosus* fragment
Pleurotoma childreni, new var.
Turritella sp.
Terebrafusus (broken), close to *costatas*, but with more spiral ribs
Nassa sp., new
Triforia sp. (Jackson)
Eulima sp.
Dentalium, probably var. of *mississippiensis*
Cadulus sp.

The maximum thickness of the Jackson recorded in the Hockley wells is 250 feet. It is doubtful whether a complete section of this formation has been penetrated in any of these wells. The thicknesses of various formations penetrated in the wells drilled at Hockley and a correlation of the sections shown by different wells are shown in Plate 9.

GEOLOGIC HISTORY OF THE DOME

There is little direct geologic evidence indicating the time when the intrusion of the salt at Hockley began. That movements have continued on this dome as late as some time subsequent to the deposition of the Lafayette is clearly evidenced, and, as previously stated, it is probable that these movements have continued well into late Pleistocene or Beaumont time.

The Lafayette, Fleming, Oligocene, and Jackson show definite tilting against the sides of the dome, and this is notably true on the northeast side. That all of these formations have been tilted from their normal positions by the intrusion of the salt is perfectly plain. If the dome movement was active in Fleming time it must have been an island around which Fleming beds were being deposited. There is little evidence that the Fleming formation around the margin of the Hockley dome contains nearshore deposits, and in view of this fact it may well be that the intrusion of this salt was not initiated until the completion of the deposition of the Fleming, which would fix the age of the initial movement as late Pliocene or even very early Pleistocene.

OIL AND GAS

As remarked in an earlier section of this paper, it was the oil encountered in a shallow well in 1902, and the seepages of gas, which resulted in the discovery of the salt core at Hockley. Notwithstanding the fact that explorations for oil on this dome have continued for a period of twenty-two years, very little in the way of actual oil production has been uncovered to date. All of the early explorations tested only the cap rock, and in a number of these wells a small quantity of oil was found, but nothing that could be considered commercial was discovered.

Texas Exploration Company's No. 1 John Warren well, on the cap rock, found showings of oil at 943 to 1,010 feet. Texas Exploration Company's No. 6 John Warren, on the cap rock, had showings of oil at 52 to 187 feet. Texas Exploration Company's No. 7 John Warren well, on the cap rock, had showings of oil from

232 to 238 feet. Texas Exploration Company's No. 8 John Warren found showings of oil in the top of the cap rock at 165 feet. Gulf Production Company's No. 2 Warren had showings of oil at intervals from 415 to 710 feet. Gulf Production Company's No. 4 Warren showed small quantities of oil at 263 to 267 feet, and at 365 feet had a gas blowout. Gulf Production Company's No. 9 Warren encountered showings of heavy oil from 77 to 90 feet.

Of the deep wells off-side, the following have had showings of oil: Texas Exploration Company's No. 2 John Warren made about two million feet of gas in a sand from 1,986 to 1,992 feet. From Texas Exploration Company's No. 4 Warren well, cores of oil-saturated sand were taken at 2,228 to 2,292 feet and at 3,912 to 3,933 feet, but this well when tested failed to yield production. Texas Exploration Company's No. 5 Warren well showed cores of oil-saturated sand at 3,883 to 3,913 feet and at 3,978 to 3,983 feet. In Texas Exploration Company's No. 10 well on the Warren lease no oil sands were found, but the gumbos between 2,175 and 2,644 feet were heavily saturated with oil. No sand was found in this interval which was capable of making production. Gulf Production Company's No. 3 Warren well reported a showing of oil at 2,519 to 2,527 feet. Gulf Production Company's No. 15 Warren well on the northeast side of the dome set 4-inch screen at 4,273 to 4,295 feet in a sand showing oil and gas. Pipe collapsed in this well and salt water broke in, ruining the well.

The most encouraging results thus far found in the off-side explorations at Hockley have been obtained in the Texas Exploration Company's wells No. 13 and No. 15 on the northeast side of the dome. No. 13 well on the Warren lease found a sand rock showing oil at 1,747 to 1,750 feet, a hard sand showing oil at 1,785 to 1,802 feet, and a sand with oil at 1,818 to 1,820 feet, immediately on top of the anhydrite. A 25-barrel well of 26-gravity oil was made in these sands. This well was completed on October 15, 1923, and is still pumping a few barrels of oil.

Texas Exploration Company's No. 15 Warren, completed on February 5, 1924, 250 feet northeast of No. 13, found the same series of oil sands encountered in No. 13 approximately 250 feet deeper. These sands were found in this well at 2,052 to 2,090 feet, and the well when completed yielded 75 barrels of oil. Water soon broke in.

While the well is still capable of yielding a small quantity of oil, production is of no great amount. The gravity of this oil is approximately 22 degrees, and the color is dark brown, as compared with the 26-gravity green oil in No. 13.

Texas Exploration Company's No. 17 Warren, located 250 feet northeast of No. 15, picked up showings of oil around 1,545 feet, and these showings continued at intervals to a depth of approximately 2,967 feet. Between 2,952 and 2,967 feet this well contained moderately coarse sand very heavily saturated with oil, but the well when tested failed to yield production.

The question is often asked as to whether Hockley will ever yield oil in commercial quantities, and as to whether this dome will enter the list of producing fields. Unfortunately, it is impossible to give a definite answer to these questions. It is argued by those who are doubtful of its possibilities that Hockley lies at the inner margin to the Gulf Coast salt-dome belt and is too far to the interior to be properly classed with the other oil-producing domes of the Gulf Coast. In other words, it is sometimes compared with the interior domes of northeast Texas in Anderson and Smith counties.

It is likewise contended by some that, owing to the fact that the Oligocene, or at least the upper portion of it, is of non-marine character, as evidenced by the absence of fossils, the chances are against obtaining production.

In answer to these arguments it can be stated that Hockley is identical in all respects with the structure of the other Gulf Coast salt domes, and has none of the features which characterize the interior domes. It has the typical cap rock and anhydrite of the other Gulf Coast salt domes, and in nearly all other respects is identical with the other producing domes. It is also no farther inland than Humble, which has yielded a greater quantity of production than any other Gulf Coast salt dome, and the geologic section penetrated by the Humble and Hockley domes is identical. However, at Humble all of the Oligocene is decidedly fossiliferous, which is not the case at Hockley.

The following may be considered adverse features of this dome from an oil-production standpoint. On the south, southeast, and southwest sides the salt appears to have penetrated the adjacent formations without tilting them at very steep angles, and likewise it has not succeeded in dragging up with it any considerable portion of the lower-lying formations. In other words, the Oligocene and Jackson have not been dragged up very high against the sides of the salt on the south, southeast, and southwest sides, as has been the case at Humble, and as is the case where the domes yield production in great quantities. Further, the Fleming and Oligocene are abnormally thick in the immediate vicinity of the Hockley dome, indicating that this structure lies well within the bottom of some synclinal depression, and this may also possibly militate against its producing capacity.

On the other hand, it is to be recognized that on the northeast side the lower formations have apparently been dragged up very much higher than is the case on the southwest side, and it is likewise to be recognized that practically one-half of the perimeter of the dome extending from the Texas Exploration Company's well No. 15 on the northeast to Texas Exploration Company's well No. 10 on the southwest has not been tested with a deep well, and nothing is known concerning the structure of this portion of the dome.

The best evidence of the productive capacity of the Hockley dome is the production that has been obtained in off-side sands in wells No. 13 and No. 15, and it is axiomatic that where there is a small quantity of oil, future drilling generally reveals more. In nearly all of these deep off-side wells there is very considerable evidence of saturation. Likewise, small quantities of oil are present in the cap rock, unquestionably proving that there must be some accumulation around the sides, else these migrations into the cap rock would not occur.

The authors are therefore of the opinion that oil in commercial quantities will sooner or later be obtained at Hockley, and from evidence now at hand it appears that the most likely area extends northwest from the Texas Exploration Company's well No. 15, around the northern perimeter of this dome.

TABLE OF WELLS

In the attached table is given a complete list of wells drilled at Hockley to date, together with a summary of the facts pertaining to them.

TABLE I

WELLS ON HOCKLEY DOME, HARRIS COUNTY, TEXAS (AS OF AUGUST 26, 1924)

Name of Well	Date of Completion	Depth (Feet)	Depth of Oil Sand (Feet)	Initial Production (Barrels)	Present Production (Barrels)	Remarks
Layne and Bowler:						
John Warren No. 1	1907–8	729	....	Dry	....	Cap rock at 237 feet; anhydrite at 237 to 541 feet; sulphur at 220 to 237 feet and 354 to 504 feet; show of oil at 112 to 133 feet, 330 to 554 feet, and 504 to 541 feet. Elevation, 163 feet
Speed:						
John Warren No. 1	....	....	....	Dry	....	Much sulphur. Elevation, 163 feet
Spear:						
John Warren No. 1	....	....	....	Dry	....	Cap rock at approximately 100 feet (?). Elevation, 185 feet
The Texas Company:						
John Warren No. 1	7/5/16	3,100	....	Dry	....	Cap rock 114 to 1,109 feet; anhydrite at 231 to 258 feet; rock salt at 1,109 to 3,123 feet. Elevation, 173 feet. Salt, 98 per cent pure
Higgins:						
John Warren No. 1	1906	730	....	Dry	....	Sulphur water at 117 feet; sandy limestone at 14 to 730 feet, with a stratum of shale with Miocene shark teeth; limestone: 60.26 per cent SiO_2, 21.42 per cent CaO. Elevation, 163 feet
John Warren No. 2	1906	863	....	Dry	....	Salt at 750 feet; sulphur at 450 to 750 feet; fresh water at 312 feet; limy shale at 312 feet; hard sandy limestone at 550 to 863 feet; no water below 400 feet. Elevation, 163 feet

TABLE I—*Continued*

John Warren No. 3	1906	545	....	Dry	....	Water at 400 feet; limy shale at 312 feet; hard sandy limestone at 438 to 545 feet; no water below 400 feet. Elevation, 172 feet
John Warren No. 4	1907	510	....	Dry	....	Bowlders at 16 feet; hard sandy limestone at 400 feet. Elevation, 163 feet
John Warren No. 5	1907	370±	....	Dry	....	Hard sandy limestone at 400 feet
John Warren No. 6	1908	630	....	Dry	....	Bowlders in shale
Gulf Production Company:						
John Warren No. 1	2/23/17	397	....	Dry	....	Sulphur at 136 to 177 feet; oil shows at 360 to 372, 379 to 381, and 388 to 393 feet. Flowed oil and black sulphur water. Elevation, 163 feet
John Warren No. 2	4/28/17	849	....	Dry	....	Cap rock at 813 feet; anhydrite at 813 to 849 feet; show of oil at 415 to 433, 435 to 445, 447 to 451, and 496 to 498 feet; gas at 704 to 710 feet. Elevation, 162 feet
John Warren No. 3	10/18/17	3,282	....	Dry	....	Oil showing at 2,519 to 2,527 feet; gas at 1,501 to 1,505, 1,575 to 1,578, and 2,743 to 2,764 feet. Elevation, 163 feet
John Warren No. 4	1/19/18	639	....	Dry	....	Cap rock at 355 to 369 feet (lost returns); oil and gas at 263 to 267 feet; gas blowout at 365 feet. Elevation, 163 feet
John Warren No. 5	5/14/18	571	....	Dry	....	Cap rock at 163 feet; anhydrite at 330 to 571 feet. Elevation, 163 feet
John Warren No. 6	2/21/19	2,985	....	Dry	....	Elevation, 164 feet
John Warren No. 7	7/3/19	2,021	....	Dry	....	Elevation, 167 feet
John Warren No. 8	....	920	....	Dry	....	Cap rock at 855 to 920 feet; anhydrite at 855 to 920 feet. Elevation, 164 feet
John Warren No. 9	3/10/20	272	....	Dry	....	Cap rock at 99 feet; anhydrite at 272 feet. Elevation, 175 feet. Show of heavy oil at 77 to 90 feet
John Warren No. 10	4/22/20	464	....	Dry	....	Cap rock at 327 feet; anhydrite at 327 to 464 feet. Elevation, 165 feet

TABLE I—*Continued*

Name of Well	Date of Completion	Depth (Feet)	Depth of Oil Sand (Feet)	Initial Production (Barrels)	Present Production (Barrels)	Remarks
Gulf Production Company:						
John Warren No. 11	6/26/20	974	....	Dry	....	Cap rock at 909 feet; anhydrite at 909 to 974 feet. Elevation, 163 feet
John Warren No. 12	11/16/20	2,247	....	Dry	....	Elevation, 163 feet
John Warren No. 13	....	3,197	....	Dry	....	Rock salt at 3,197 feet. Elevation, 162 feet
John Warren No. 14	....	567	....	Dry	....	Porous rock at 567 feet. Elevation, 170 feet
John Warren No. 15	?/?/22	4,302	....	Dry	....	Salt water at 4,302 feet; 4-inch screen set at 4,273 to 4,295 feet in formation showing oil and gas; pipe collapsed and salt water broke in. Elevation, 167 feet
John Warren No. 16	....	800	....	Dry	....	Cap rock at 338 feet. Elevation, 163 feet
John Warren No. 17	....	....	....	Dry	....	Cap rock at 219 feet; anhydrite at 219 feet. Elevation, 163 feet
John Warren No. 18	....	....	....	Dry	....	Cap rock at 131 feet; rock salt at 1,059 feet. Elevation, 163 feet
John Warren No. 19	....	....	....	Dry	....	Cap rock at 265 feet; rock salt at 1,030 feet. Elevation, 175 feet
Texas Exploration Company:						
John Warren No. 1	2/17/20	1,145	....	Dry	....	Cap rock at 872 to 1,080 feet; anhydrite at 1,080 to 1,114 feet; rock salt at 1,114 to 1,145 feet; sulphur show at 942, 954, 1,010, 1,015, and 1,038 feet; oil show at 943, 954, 960, and 1,010 feet. Elevation, 172 feet
John Warren No. 2	1/18/21	3,750	....	Dry	....	Black shale at 3,711 to 3,750 feet; 2,000,000 feet gas at 1,986 to 1,992 feet. Elevation, 172 feet
John Warren No. 3	12/31/20	2,136	....	Dry	....	Sulphur trace at 1,690 feet. Elevation, 185 feet

TABLE I—*Continued*

John Warren No. 4	1/20/22	4,412	....	Dry	....	Black shale at 4,282 to 4,412 feet; oil show at 2,270, 2,288, 3,917, 3,923, 3,924, 3,930, and 4,162 feet. Elevation, 168 feet
John Warren No. 5	10/28/22	4,380	....	Dry	....	Black shale at 3,670 to 4,380 feet; oil show at 3,883 to 3,983 feet. Elevation, 171 feet
John Warren No. 6	6/22/22	195	....	Dry	....	Cap rock at 187 to 192 feet; black shale at 21 to 24 and 168 to 171 feet; sulphur water at 187 feet; oil show at 52, 110, 174, 178, and 187 feet. Elevation, 171 feet
John Warren No. 7	10/21/22	1,088	....	Dry	....	Cap rock at 252 feet; anhydrite at 252 to 1,080 feet; rock salt at 1,080 to 1,088 feet; oil show at 232 and 238 feet. Elevation, 171 feet
John Warren No. 8	11/8/22	172	....	Dry	....	Cap rock at 165 feet, with oil show. Elevation, 172 feet
John Warren No. 9	12/4/22	419	....	Dry	....	Elevation, 203 feet
John Warren No. 10	8/10/23	3,956	....	Dry	....	Oil show at 2,175 to 2,397 feet; good gas show at 2,584 feet. Elevation, 173 feet
John Warren No. 11		183	....	Dry	....	Cap rock at 183 feet. Elevation, 185 feet
John Warren No. 12	1/20/22	261	....	Dry	....	Cap rock at 186 feet; show of oil. Elevation, 180 feet
John Warren No. 13	2/7/23 10/15/23	1,821	1750–1820	25	....	Anhydrite at 1,820 feet; oil sand at 1,552 feet. Elevation, 190 feet
John Warren No. 14	9/30/23	137	....	Dry	....	Cap rock at 101 feet; anhydrite at 135 feet. Elevation, 185 feet
John Warren No. 15	2/5/24	2,090	2052–2090	75	....	Elevation, 187 feet
John Warren No. 16	1/29/24	150	....	Dry	....	Elevation, 187 feet
John Warren No. 17	8/25/24	3,039	2945–2976	Dry	....	Anhydrite. Elevation, 186 feet
John Warren No. 18	?/?/24	600	....	....	....	Elevation, 188 feet
John Warren No. 19	7/28/24	375	....	....	....	Showing of oil at 136, 201, and 287 to 309 feet; anhydrite at 368 feet
John Warren No. 20	....	....	....	....	....	Drilling at 400 feet on September 8, 1924

SULPHUR

The thick limestone cap at Hockley would appear to be favorable to the occurrence of sulphur. While a number of showings of sulphur have been obtained in various wells drilled at Hockley, it cannot be stated at this time that there is a commercial deposit of sulphur in the Hockley dome. Whatever sulphur is present is probably spotted, though considering the large area of this cap rock, it is possible that small tracts of 25–50 acres in extent may contain sulphur in sufficient quantities to justify exploitation.

The following wells have been reported as showing sulphur: Texas Exploration Company's No. 1 Warren has shown sulphur at 942 to 1,048 feet. Layne and Bowler's well No. 1 Warren encountered sulphur-bearing rock at 222 to 237 feet and at 354 to 504 feet. The so-called Speed well was reported to have shown much sulphur. Gulf Production Company's No. 1 Warren well encountered sulphur-bearing rock at 136 to 177 feet.

There is still a considerable portion of the cap rock untested for sulphur. As will be noted from map (Fig. 3), no well has penetrated this rock in the area outlined by the Spear well, Gulf Production Company's wells No. 9 and No. 17, Layne and Bowler's No. 1 Warren, Gulf Production Company's No. 5 Warren, and Texas Exploration Company's No. 7 Warren and No. 8 Warren. This area includes approximately 640 acres of land, and what might be developed in the way of sulphur by exploring this portion of the cap rock remains to be seen.

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THE BLUE RIDGE SALT DOME, FORT BEND COUNTY, TEXAS[1]

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ABSTRACT

The Blue Ridge salt dome is a characteristic Gulf Coast salt dome and has a topographic mound, a stocklike salt core, a "lime" (gypsum) anhydrite cap, and steeply dipping beds on the flanks. The stratigraphic relations have been worked out by micropaleontologic studies. The beds penetrated by the drill are Pleistocene to Jackson in age. Modest, somewhat freaky production has been established. The gravity of the oil ranges from 18° to 46° Baumé, and on the average is around 28° Baumé. The production is from flank sands.

LOCATION

The Blue Ridge salt dome is in the eastern part of Fort Bend County, close to the Harris County line, Texas. It is 15 miles southwest of Houston, and 2 miles south of Missouri City. The Houston-Richmond pike runs through Missouri City, and dirt roads lead south from this highway to the field.

HISTORY

Blue Ridge comprises two low hills of about 20 feet elevation, lying some 3,500 feet apart on a northwest-southeast axis. On account of these two surface mounds, the Rio Bravo Oil Company drilled a test well (1)[2] in 1903, in the southwest corner of the Edward Drew survey, to a depth of 1,420 feet. Oil shows were encountered from 153 feet to the bottom; gypsum and lime at intervals from 156 to 790 feet, where lime and salt were found. At 820 feet, the main salt body was reached, and the well was abandoned in salt at 1,420 feet.

After the Rio Bravo test had proved the salt-dome character of the area, other operations were soon undertaken. Few ventured far from the first test. Beatty and House, of Houston, drilled the second well (2). It was 300 yards west of the Rio Bravo boring. Only insignificant shows of oil and gas were found, and the well was abandoned in salt and "lime" formation at 820 feet.

Next, Hager and Josey drilled a well (3) early in 1905, in Lot 4, Block E, Edward Drew survey. It was taken over by the Blue Ridge Oil and Development Company, composed of Houston men, and completed at a depth of 900 feet, where it stopped in rock salt. Their No. 1 Blakeley (4), Lot 3, Block E of same survey, stopped in salt at 1,000 feet. This company drilled five wells in the southeast part of the Drew survey before applying for a receivership in 1906.

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[1] The writers are indebted to Don F. McIntosh, Gulf Production Company, for a large part of the information on the history and production of the field; to C. R. Carter for the drafting on the accompanying maps and sections.

[2] Numbers in parentheses following names of wells refer to index map and list.

Early in 1907, the Valley Ridge Oil Company drilled a well in Lot 4, Block E, Drew survey, to 1,240 feet, and abandoned the test at that depth in salt. Showings of 17° Baumé gravity oil were reported from 700 feet. In the fall of 1907, the Daylight Oil Company drilled two wells, of which No. 1 was lost with casing twisted off, and No. 2 abandoned on account of water trouble at 1,132 feet. These were located 4,000 feet north of the wells in Lot 4, Block E, Drew survey. The Producers Oil Company took over the holdings of the Daylight Oil Company and in 1908 drilled Blakeley No. 1 (5) in the north part of the Drew survey to a depth of 1,100 feet; J. S. Stewart completed this well to 1,600 feet. Its only showing was a heavy asphaltum at 1,272 feet. J. S. Stewart *et al.*, in 1908, completed another well (6) at a depth of 1,300 feet near the center of Lot 8, Block C, Drew survey. It had a slight show at 1,200 feet. Both these tests were off the dome.

During the years 1909 to 1913, operations ceased at Blue Ridge. In the summer of 1914, the Blue Ridge Oil and Gas Company drilled two wells on the Blakeley land. Their No. 1 (7), Lot 6, Block C, Drew survey, was junked at 1,900 feet. The derrick was moved 55 feet north and, on Lot 7, a hole (8) sunk to 1,846 feet. Both these wells were to the north of the dome and had no oil shows of importance. Their third well (9), Lot 7, Block A, Robinson subdivision, was drilled to 700 feet; salt was reached at 640 feet.

In 1917, the Blue Ridge Development Company, including Esperson *et al.*, drilled No. 1 Adams (10) in the southwest corner of A. J. Adams subdivision, Thos. Habermaker survey, to 874 feet. Rock salt was reached at the shallow depth of 246 feet. In the same year, their No. 1 Robinson (11) was completed to a depth of 2,080 feet. This was southwest of the dome on the T. J. Ewing tract in the Hicks Shropshire survey. No showings were found.

In 1918, the Gulf Production Company entered the field. Their first well, No. 1 Robinson (12), was a dry hole, 3,328 feet deep. It was near the northeast corner of the Hicks Shropshire survey, north of the salt. Their next test, No. 1-C Blakeley (13), in the central eastern part of Lot 3, Block E, Drew survey, lost returns and was abandoned in salt water at 435 feet. In April, 1919, their third well, No. 2-C Blakeley (14), located 900 feet northeast of the second test, in Lot 3, Block F, Drew survey, came in flowing 1,200 barrels per day by heads, at 2,700 feet. The gravity of this oil was 29.3° Baumé. It distilled considerable kerosene, but little gasoline. This was the first commercial well in the field. Although it was considered rather a freak well, it drew the attention of large producers to the field and brought on a more systematic drilling campaign. As much as $700 an acre was paid for acreage more than 1,000 feet from the well. By the end of the year, eight of the larger operators were engaged in active development, among them the Gulf Production Company, The Texas Company, Sinclair Oil Company, Republic Production Company, West Production Company, and R. C. Duff.

In 1919, the Gulf Production Company completed Luscher Nos. 1 (14) and 2 (15) as small pumpers. During 1920, development was active on the eastern side of the dome, and continued to about the fall of 1921. Some drilling continued during 1922 and 1923. On the west side of the dome, development became very active in the late fall of 1920 when The Texas Company completed No. 1 Robinson (40) in the latter part of October, for 5,000 barrels of fluid, 50 per cent water. The intense drilling continued in 1921. The main development was on 1-acre lots of blocks 2, 3, 13, and 14, Robinson subdivision, Shropshire survey. As high as $10,000 for 1 acre was paid. In general, the sands on the west side proved freaky; they were thin and pinched out sharply. Interest rapidly slackened. In June, 1923, The Texas Company revived it by bringing in their No. 10 Robinson (94), farther northwest, for 3,000 barrels per day. By December, this well was pumping 150 barrels per day.

At the present time, three wells are being drilled at Blue Ridge.

PHYSIOGRAPHY

The Blue Ridge mound covers approximately 1,000 acres, and rises to a height of about 20 feet above the surrounding country. Its shape is shown on the accompanying topographic map, which was made by the Roxana Petroleum Company (Fig. 1). Its axis strikes northwest and southeast. There are two flat hills on the dome, about 3,500 feet apart, with an intervening low area. It is interesting to note that the depression on the surface overlies the highest part of the salt core. This topographic low was probably caused by the leaching out of the top of the salt by surface waters.

GEOLOGY

Blue Ridge is a typical Gulf Coast salt dome, composed of a salt core intruded through the surrounding shales and sands and surmounted by cap rock.

The shape of the salt core is elliptical, as indicated by the wells which have been drilled into salt. Such wells show the salt to extend approximately 1.5 miles along the northwest-southeast axis, and 1 mile at right angles to this axis. As can be seen from the cross-sections, the depth to the salt varies from 143 feet on top of the dome to over 3,500 feet on the flanks. The top of the salt core slopes gently, but the sides dip sharply. The three sections across the dome, shown in Figure 2, serve to bring out the shape of the salt core.

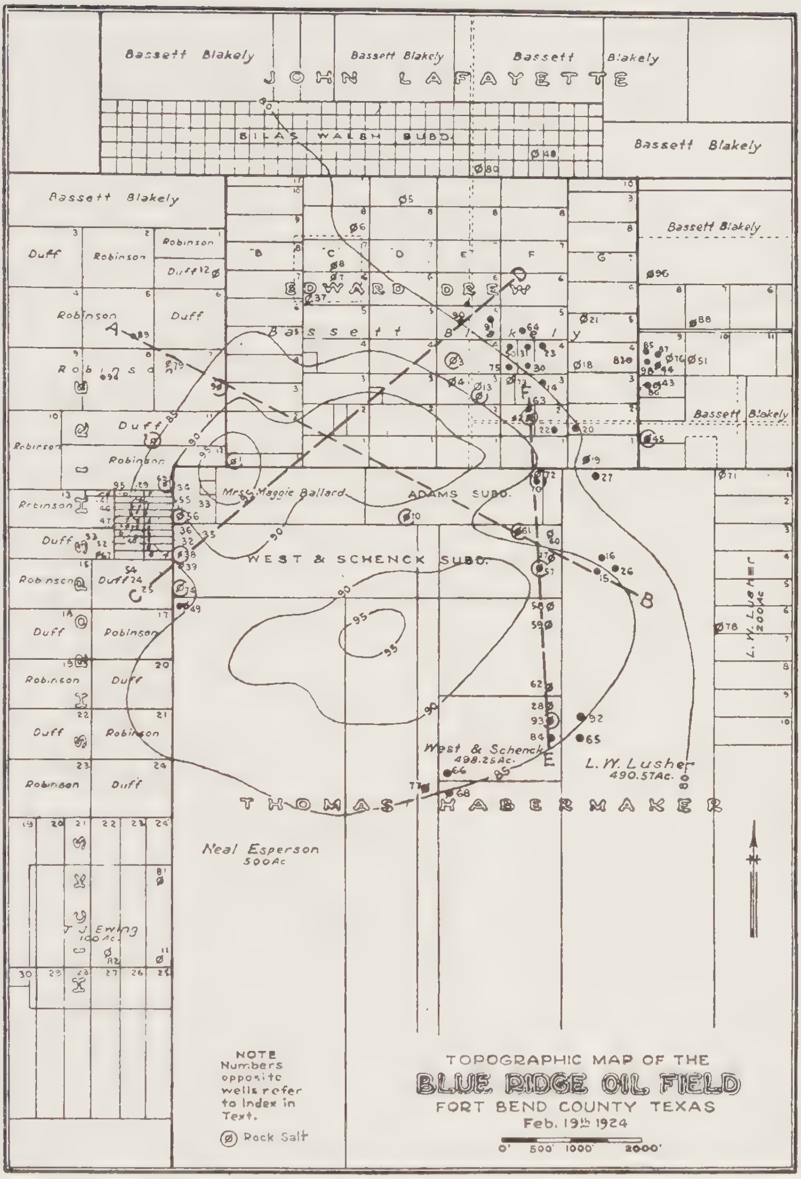

FIG. 1.—Topographic map of the Blue Ridge salt dome

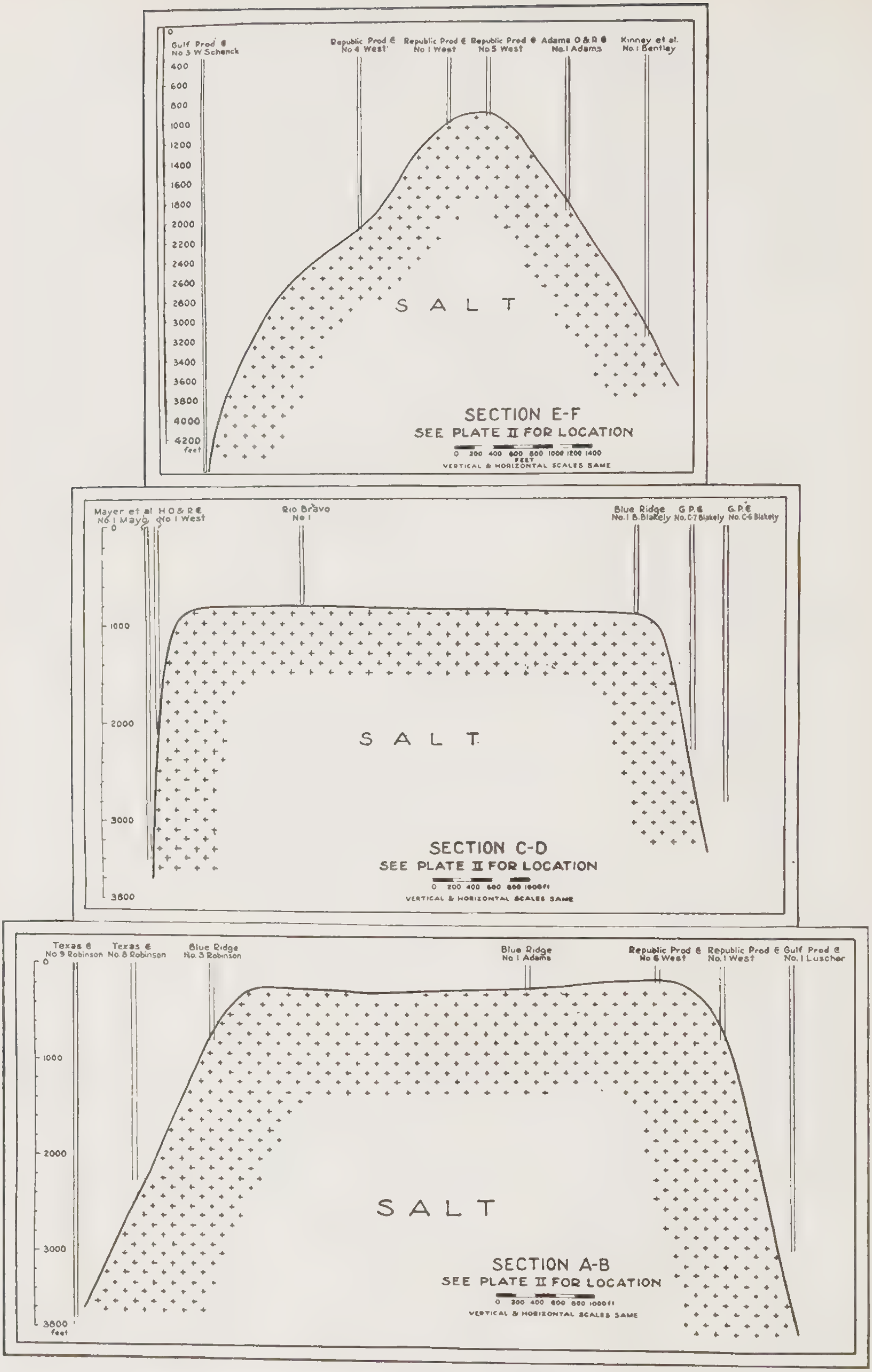
Gulf Prod € No 3 W Schenck
Republic Prod € No 4 West
Republic Prod € No 1 West
Republic Prod € No 5 West
Adams O & R € No 1 Adams
Kinney et al. No 1 Bentley
0
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
feet
SALT
SECTION E-F
SEE PLATE II FOR LOCATION
0 200 400 600 800 1000 1200 1400
FEET
VERTICAL & HORIZONTAL SCALES SAME
Mayer et al No 1 Mayo
H O & R € No 1 West
Rio Bravo No 1
Blue Ridge No. 1 B. Blakely
G P € No. C-7 Blakely
G P € No. C-6 Blakely
0
1000
2000
3000
3800
SALT
SECTION C-D
SEE PLATE II FOR LOCATION
0 200 400 600 800 1000 ft
VERTICAL & HORIZONTAL SCALES SAME
Texas € No 9 Robinson
Texas € No. 8 Robinson
Blue Ridge No. 3 Robinson
Blue Ridge No 1 Adams
Republic Prod € No 6 West
Republic Prod € No. 1 West
Gulf Prod € No. 1 Luscher
0
1000
2000
3000
3800
feet
SALT
SECTION A-B
SEE PLATE II FOR LOCATION
0 200 400 600 800 1000 ft
VERTICAL & HORIZONTAL SCALES SAME

FIG. 2.—Cross-sections of the salt core. For the position of the sections see Figure 1

The outline of the salt in these sections is more or less hypothetical, inasmuch as there are not enough wells drilled on the top of the dome to define its shape. The top of the salt along the northwest and southeast axis, Section *A-B*, is relatively broad and flat. This is also true along the northeast-southwest axis, Section *C-D*. At the southeast end of the field, Section *E-F*, in a north-and-south direction, shows the top of the salt to be narrow and rounded.

The cap rock is not found in wells drilled away from the salt core. It is best developed on the dome. The cap consists of "lime" and gypsum with salt interbedded, and pyrites; in some wells it had shows of oil and sulphur. In one well, the Adams Oil Co. No. 1 Adams (70), it produced some oil. In Republic Production Co.'s No. 6 West (61) there were 87 feet of salt and gypsum; in the No. 5 West (60), 179 feet of salty shale, "lime," and "gyp" rock; in the No. 2 West (57), only 60 feet of soft gypsum; and in No. 1 West (17), 109 feet of gypsum and salt. In the Rio Bravo Oil Co. No. 1, there were 450 feet of "lime," pyrites, gypsum, and salt interbedded. These figures indicate that the cap rock is thicker toward the top of the dome, wedges out toward the edges, and finally disappears. On the higher parts of the dome, part of it has possibly been eroded.

On the east side of the salt, the oil sands dip away from the core at angles of 35° to 45°, as measured between the Gulf Production Co. Bassett Blakeley No. 2-C (14) and the Oil Production Co. No. 1 Lee-Bashara (98). On the west side, the dip seems to be greater, especially close to the salt. Paleontological examination of cuttings from wells, discussed under "Stratigraphy," indicates that on the west side of the dome this sharp dip diminishes within a short distance away from the salt. The dip on the base of the Fleming between The Texas Co. Robinson No. 9 (89) and No. 10 (94) is 380 feet in a distance of 760 feet, or at the rate of 27° to the southwest; from Robinson No. 10 to the Mutual Oil Co. No 1 Weems (97), the base of the Fleming dips 364 feet in a distance of 1,300 feet, or at the rate of 16°.

STRATIGRAPHY

The data in regard to stratigraphy of the Blue Ridge field were secured through courtesy of the paleontological departments of The

Texas Co. and the Humble Oil and Refining Co., and apply chiefly to the area west of the salt.

The surface formations at Blue Ridge are Pleistocene in age. Except on top of the salt core, the thickness of these beds is fairly uniform. They consist of 500 feet of clays, sands, and gravels, the upper part of which belongs to the Beaumont or Coast clays, the lower part to the Lafayette or Lissie gravels.

The top of the Fleming, which embraces the Pliocene-Miocene formations, is about 500 feet below the surface in Robinson No. 10, the base at 3,800 feet. Aragonitic prisms and re-worked Foraminifera are typical of this formation. The upper 1,000 feet of the Fleming are mainly gumbo, sand, and bowlders; the middle and lower parts, from 1,400 to 3,760 feet, contain much lime, with shales and bowlders. The oil sand at 3,900 feet is in the top of the Oligocene. In No. 9 Robinson (89), the base of the Fleming is placed at 3,470 feet.

The Oligocene in No. 9 Robinson extends from 3,470 feet to the bottom of the well at 3,892 feet. The Oligocene consists here of gray sand and shale, and some pyrite and glauconite. At 3,867 feet, anhydrite was found, possibly in the cap. The production is from the upper part of the Oligocene. In the Mutual Oil Co. No. 1 Weems (97), the Fleming-Oligocene contact was at 4,229 feet, and the well is still in Oligocene at 4,450 feet, the present depth of the well. Samples from that depth show fine gray sand. In The Texas Co. No. 1 Robinson (40), which is closer to the salt than wells previously mentioned, the base of the Oligocene is at 3,410 feet, and consists of gray marly clay. A sample at 3,662 feet was determined as being from low in the Jackson formation.

A sample from the Humble Oil and Refining Co. No. 1 Damon Mound (32), at 3,507 feet, was determined as Miocene; Oligocene extended from 3,649 feet to the bottom of the hole. The same company's Dew No. 1 (33) was still in Miocene at 3,238 feet, and their West No. 2 (74) was in the Miocene, or the lower part of the Fleming, from 1,730 to 2,862 feet. Scattered samples from 2,862 to 2,866 feet in this well showed Oligocene fossils; and one sample from 3,051 to 3,246 was of Jackson or upper Eocene age. The Oil Issues Co. No. 1 Booth (54) had Oligocene at 3,897 to 3,907 feet.

On the east side of the dome, the Kirby Petroleum Co. No. 2 Lee-Blakeley (85) had Oligocene at 3,741 feet, and the Sinclair Oil

Co. No. 1 Lee-Bashara (44) was in Oligocene at 3,655 feet. In neither case did the sample indicate the top of the Oligocene.

On the west side of the field, the oil is coming from sands in the upper part of the Oligocene. This may hold true for the eastern part of the field, but sufficient paleontological work has not yet been done in that area.

OIL AND GAS

The field was first tested on account of the mound. Gas or oil seeps were not found at Blue Ridge.

The character of the oil at Blue Ridge varies. On the western flank of the dome, the gravity is from 28.5° to 31° Baumé; in the northeast area, from 18.4° to46° Baumé. The best wells there produce oil of 24.4° to 29° Baumé gravity. The oils of extremely high or low gravities are found only in freak wells. In the southeastern area, the gravity of the oil ranges from 22.4° to 23.5° Baumé. This is a typical Gulf Coast crude. The wells there on the average are the best in the whole field.

In the western area, the oil for the most part is found in sharply dipping beds close to the salt. The wells usually came in flowing from several hundred to several thousand barrels per day. Within twenty-four hours, or at most a few days, the wells generally settled to steady flowing wells or pumpers of about 100 to 150 barrels per day, continued to produce from several months to a year, and then sanded up and were abandoned. A production curve for the Humble Oil and Refining Co. No. 1 Damon Mound (32) is shown in Figure 3.

In the northeastern part of the field the production of the 24° to 29° Baumé gravity wells generally came in for a few hundred to several thousand barrels per day. Some of them flowed several hundred barrels per day for months and then made good pumpers of 60 to 90 barrels or less per day. Figure 3 includes a production curve of the Gulf Production Co. No. 2-C Blakeley (14).

In this section of the field several wells have also come in making high-gravity oil; also one of low gravity. The Gulf Production Co. No. 4 Luscher (27) produced 39° Baumé gravity oil. This well came in flowing 300 barrels per day. For the first month, the well averaged 166 barrels per day. It decreased gradually until at the end of the first year it was producing about 8 barrels per day. At the end of the second year it was still producing from 2 to 2½ barrels per day. The

Sinclair Oil Co. Davidson No. 2 (86) came in flowing 300 barrels per day of 42° Baumé gravity oil at 3,226 feet. Three and a half months later, it was producing 120 barrels daily; a year and nine months later, it was still making 30 barrels daily. The Texas Co. Fee No. 2 (75) was a small pumper of 18.4° Baumé gravity oil. It came in for 30 barrels and went up to 80 barrels per day; at the end of six months it was pumping 10 barrels per day. It was probably in a sandy lens fairly close to the salt.

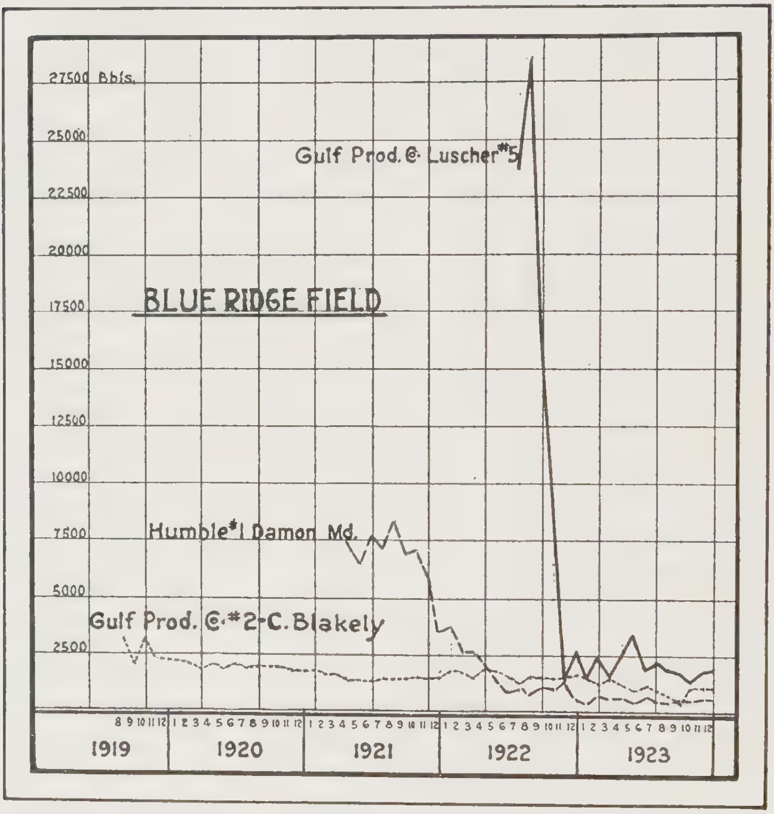

FIG. 3.—Curves of monthly production for Gulf Production Co. Luscher No. 5 and Blakeley No. 2-C and for Humble Oil and Refining Co. Damon Mound No. 1.

The production in the northeast area is from hard sand and sandy shale, away from the flank of the salt. In some logs, only sandy shale is shown. The pay ranges in thickness from 40 feet to over 100 feet; the sand ranges from 10 to 40 feet, or over, and the rest of the pay is sandy shale.

In the southeastern area, the oil is found in beds close to the salt. As already stated, it is typical Gulf Coast crude, and the wells are the best in the field. To date only a few wells have been drilled there. Of these only three are producing at present: the Gulf Production Co. Luscher No. 5 (65) and No. 6 (92), and West-Shenck No. 3 (84). The production curve of Luscher No. 5, which is typical of this area, is shown in Figure 3.

No paying production has been found in the cap rock. The Adams Oil Co. No. 1 Adams (70) flowed 100 barrels for one day of 32° Baumé gravity oil from the top of the cap at 848 feet. It was not possible to pump this well, as there was no fluid in the hole. After being drilled 3 feet deeper, the well pumped 10 barrels for one day and then averaged about 2 barrels per day for a week, when it stopped pumping. Although shows were had in the cap rock, sulphur was not found in commercial quantity.

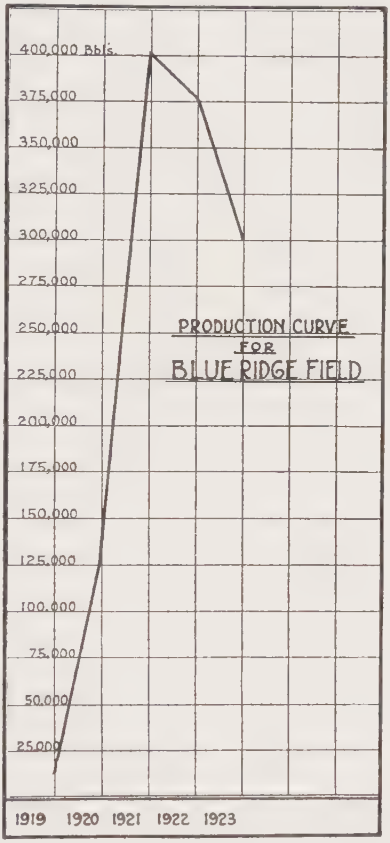

FIG. 4.—Curve of yearly production for the whole field.

The production curve for the entire field up to January, 1924, is given in Figure 4.

The Gulf Production Co. at present runs most of the oil from the field through its 6-inch line. The oil is refined at Port Arthur. The Sinclair Co. has an 8-inch line from the field $1\frac{1}{4}$ miles eastward to a loading-rack at Almeda, on the I. & G. N. Railroad. The Texas Co. has a loading-rack on the Southern Pacific Railroad.

TABLE I

Temperature (F.)	Percentage	Gravity Baumé	Remarks
Blakeley No. 1, Blue Ridge Production Co. (Kavanaugh & West)			
146°–248°	10	58.5°	Crude, 44.5° Baumé Over-point, 146° F. Gravity of total distillate (79 per cent), 48.4° Baumé Distillation loss, 1 per cent
248 –275	10	54.4	
275 –302	10	52.0	
302 –319	10	49.9	
319 –364	10	47.8	
364 –413	10	45.2	
413 –461	10	41.6	
461°–500°	9	37.7	
Residue	20	30.6	
Blakeley No. 2-C, Gulf Production Co.			
167°–308°	10	59.5°	Crude, 29.3° Baumé Over-point, 167° F. Gravity of total distillate (37.5 per cent), 43.3° Baumé Distillation loss, 1.3 per cent
308 –369	10	46.6	
369 –462	10	36.4	
462°–500°	7.5	30.5	
Residue	61.2	21.6°	
Pilant No. 1, Gulf Production Co.			
164°–278°	10	53.4°	Crude, 30.4° Baumé Over-point, 164° F. Gravity of total distillate (52 per cent), 38.9° Baumé Distillation loss, 1 per cent
278 –325	10	46.1	
325 –384	10	39.6	
384 –443	10	33.3	
443 –495	10	29.6	
495°–500°	2	....	
Residue	47	20.3°	
Luscher No. 5, Gulf Production Co.			
254°–450°	10	41.0°	Crude, 23.7° Baumé Over-point, 254° F. Gravity of total distillate (23 per cent), 35.6° Baumé Distillation loss, 0.17 per cent
450 –515	10	32.5	
515°–527°	3	29.7	
Residue	76.83	20.9°	

Analyses of the oil from Blue Ridge, made by E. T. Gregg and F. M. Seibert of the Gulf Pipe Line Laboratory, Houston, Texas, are given in Table I. The first is of an oil from the western side of the dome, the second of a typical oil from the northeast section, the third of a high-gravity oil from the same area; and the last is of a typical oil from the southeast side of the dome.

TABULAR LIST OF WELLS

Table II gives a list of the wells drilled in the field, showing owner, farm, total depth, date of completion, initial production, and

TABLE II

Map No.	Company	Well	Total Depth (Feet)	Date Completed	Initial Production (Barrels)*	Present Production (Barrels Daily)
1	Rio Bravo Oil Co.	No. 1	1,420	....	S at 820 ft.	....
2	Beatty & House	No. 1	820	....	....	....
3	Blue Ridge O. & D. Co.	....	900	....	S at 900 ft.	....
4	Blue Ridge O. & D. Co.	No. 1 Blakeley	1,000	....	S at 1,000 ft.	....
5	Producers Oil Co.	No. 1 Blakeley	1,600	....	....	....
6	J. S. Stewart *et al.*	....	1,300	....	....	....
7	Blue Ridge O. & G. Co.	No. 1 Blakeley	1,900	....	....	....
8	Blue Ridge O. & G. Co.	No. 2 Blakeley	1,846	....	....	....
9	Blue Ridge O. & G. Co.	No. 3 Robinson	700	....	....	....
10	Blue Ridge O. & G. Co.	No. 1 Adams	874	....	....	....
11	Blue Ridge O. & G. Co.	No. 1 Robinson	2,080	....	....	....
12	Gulf Production Co.	No. 1 Robinson	3,328	....	....	....
13	Gulf Production Co.	No. 1-C Blakeley	435	....	....	....
14	Gulf Production Co.	No. 2-C Blakeley	2,700	4–4–19	1,200	43
15	Gulf Production Co.	No. 1 Luscher	2,720	....	....	....
16	Gulf Production Co.	No. 2 Luscher	2,696	6–13–20	P 25	5
17	Republic Production Co.	No. 1 West	2,000	....	S at 621	....
18	Gulf Production Co.	No. 1-B Blakeley	2,913	....	SW	....
19	Gulf Production Co.	No. 2-B Blakeley	2,817	5–24–20	P 75	....
20	Gulf Production Co.	No. 3-B Blakeley	2,974	1–29–21	250	16
21	Gulf Production Co.	No. 4-B Blakeley	4,155	....	....	....
22	Gulf Production Co.	No. 3-C Blakeley	2,750	10–14–20	1,500	....
23	Gulf Production Co.	No. 4-C Blakeley	2,696	4–12–21	1,000	....
24	Gulf Production Co.	No. 1 Goodman	2,673	....	....	....
25	Gulf Production Co.	No. 2 Goodman	2,718	....	....	....
26	Gulf Production Co.	No. 3 Luscher	2,938	2–5–21	P 40	5
27	Gulf Production Co.	No. 4 Luscher	2,645	1–3–21	300	4
28	Gulf Production Co.	No. 1 West-Shenck	3,481	....	SW	....
29	Gulf Production Co.	No. 1 Pilant	3,633	1–26–21	500	....
30	Gulf Production Co.	No. 2 Blakeley	2,538	3–13–21	150	33
31	Gulf Production Co.	No. 1 Blakeley	2,695	10–20–20	3,500	....
32	Humble Oil & Rfg. Co.	No. 1 Damon Mound	3,947	3–9–21	276	15
33	Humble Oil & Rfg. Co.	No. 1 Dew Bros.	3,301	2–15–21	600	....
34	Humble Oil & Rfg. Co.	No. 2 Dew Bros.	3,200	3–9–21	1,912	....
35	Humble Oil & Rfg. Co.	No. 1 Myers	3,532	....	....	....
36	Humble Oil & Rfg. Co.	No. 1 Pearson	2,967	1–12–21	300	....
37	Humble Oil & Rfg. Co.	No. 1 Blakeley	4,157	....	....	....
38	Humble Oil & Rfg. Co.	No. 1 West	2,315	....	S at 2,142 ft.	....
39	Mayer *et al.*	No. 1 Mayo	3,479	....	....	....
40	The Texas Co.	No. 1 Robinson	4,112	10–24–20	5,000 ½SW	....
41	Kavanaugh Pet. Co.	No. 1 Isbell	880	....	....	....
42	Kinney *et al.*	No. 1 Bentley	2,779	....	....	....
43	Sinclair Oil Co.	No. 1 Davidson	3,350	....	....	....
44	Sinclair Oil Co.	No. 1 Lee-Bashara	3,832	....	....	....
45	Blue Ridge Prod. Co.	No. 1 Blakeley	3,924	....	S at 1,000 ft.	....
46	Crown Oil & Rfg. Co.	No. 1 Johnson	3,531	....	S at 3,333 ft.	....
47	Crown Oil & Rfg. Co.	No. 1 Ransom	3,700	....	....	....
48	Deep Blue Ridge Oil Co.	No. 1 Blakeley	3,235	....	....	....
49	Invincible Oil Co.	No. 1 Esperson	3,960	6–3–21	500	4
50	Bennett, Jones, McClanahan	No. 1 Texas Co.	2,894	1–21–21	500	....
51	R.C. Duff	No. 1 Soderberg	4,445	....	....	....
52	Mutual OilCo.	No. 1 Booth	3,952	6–. .–21	2,000	28
53	Oil Issues Co.	No. 2 Booth	3,517	....	....	....
54	Oil Issues Co.	No. 1 Booth	868	....	....	....
55	Republic Production Co.	No. 1 Booth	3,300	....	S at 3,300 ft.	....
56	Republic Production Co.	No. 1 Callahan	3,200	....	S at 2,402 ft.	....
57	Republic Production Co.	No. 2 West	505	....	S at 450 ft.	....
58	Republic Production Co.	No. 3 West	2,000	....	S at 2,000 ft.	....
59	Republic Production Co.	No. 4 West	1,700	....	S at 1,700 ft.	....
60	Republic Production Co.	No. 5 West	705	....	S at 560 ft.	....
61	Republic Production Co.	No. 6 West	230	....	S at 143 ft.	....
62	Republic Production Co.	No. 7 West	2,755	....	....	....
63	Taylor Oil Co.	No. 1 Blakeley	2,116	....	....	....
64	Gulf Production Co.	No. 5-C Blakeley	3,038	5–20–21	300	....
65	Gulf Production Co.	No. 5 Luscher	4,009	7–12–22	1,500	68

* The symbols in this column have respectively the following meanings: S = show of oil, SW = salt water, P = pumped. If the initial production is given without the P, the well came in flowing.

TABLE II—*Continued*

Map No.	Company	Farm	Total Depth (Feet)	Date Completed	Initial Production (Barrels)*	Present Production (Barrels Daily)
66	Gulf Production Co.	No. 2 West-Shenck	3,914	9-19-21	P 40	....
67	The Texas Co.	No. 7 Robinson	4,593	....	....	....
68	Amerada Petroleum Co.	No. 1 West-Shenck	3,505	....	....	....
69	The Texas Co.	No. 3 Robinson	639	....	S at 639 ft.	....
70	Adams Oil & Dev. Co.	No. 1 Adams	1,444	....	S at 1,444 ft.	....
71	West Production Co.	No. 1 Luscher	3,340	....	....	....
72	Adams Oil & Dev. Co.	No. 2 Adams	767	....	....	....
73	Baker Oil Co.	No. 1 Bentley	1,584	....	....	....
74	Humble Oil & Rfg. Co.	No. 2 West	3,483	....	S at 3,406 ft.	....
75	Jones, McClanahan	No. 2 Texas Co.	1,672	3-2-21	P 30	....
76	Kirby Petroleum Co.	No. 1 Bashara	4,413	....	....	....
77	Sinclair Oil Co.	No. 1 West-Shenck	3,124	....	....	....
78	Turnbow Petroleum Co.	No. 1 Christian	4,336	....	SW	....
79	The Texas Co.	No. 8 Robinson	2,243	....	....	....
80	Blue Ridge Oil Co.	No. 1 Blakeley	2,638	....	....	....
81	Neil Esperson	No. 2 Ewing	3,904	....	....	....
82	Neil Esperson	No. 1 Ewing	5,278	....	....	....
83	Gulf Production Co.	No. 5-B Blakeley	3,935	4-30-22	50	....
84	Gulf Production Co.	No. 3 West-Shenck	3,979	10-14-22	2,600	177
85	Kirby Petroleum Co.	No. 2 Lee	3,981	5-14-22	2,500	....
86	Sinclair Oil Co.	No. 2 Davidson	4,106	3-31-22	300	20
87	Sinclair Oil Co.	No. 2 Bashara	3,996	12-7-22	140	....
88	Sinclair Oil Co.	No. 1 Lee-Smith	4,136	....	....	....
89	The Texas Co.	No. 9 Robinson	3,892	....	S at 3,729 ft.	....
90	Gulf Production Co.	No. 7-C Blakeley	2,278	4-24-23	250	5
91	Gulf Production Co.	No. 6-C Blakeley	2,771	3-2-23	200	....
92	Gulf Production Co.	No. 6 Luscher	3,815	5-22-23	2,000	124
93	Gulf Production Co.	No. 4 West-Shenck	3,622	....	S at 3,413 ft.	....
94	The Texas Co.	No. 10 Robinson	3,900	6-13-23	3,000	76
95	Blue Ridge Prod. Co.	No. 1 Robinson	4,004	....	....	....
96	The Texas Co.	No. 1 Blakeley	3,619	....	....	....
97	Mutual Oil Co.	No. 1 Weems	4,450	Drilling	....	....
98	Oil Production Co.	No. 1 Lee-Bashara	4,029	1-12-22	4,000	....

* The symbols in this column have respectively the following meanings: S=show of oil, SW=salt water, P=pumped. If the initial production is given without the P, the well came in flowing.

present production. The index-map numbers are in general chronological order with reference to the commencement of wells, but no attempt was made to get an exact chronological sequence.

THE DAMON MOUND OIL FIELD, TEXAS

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ABSTRACT

Damon Mound is a conspicuous rounded elevation in northwestern Brazoria County, Texas, 38 miles southwest of Houston. It is oval in shape, covers an area of 1,670 acres and rises 83 feet above the surrounding prairie. This elevation is the result of an intrusive salt plug which has raised the surface above its normal position.

The salt plug is composed of almost pure rock salt and is capped by deposits of gypsum, anhydrite, and limestone. Formations surrounding the salt plug are inclined at angles of about 45° away from the salt plug. Mineralized water and gas seepage in shallow water wells, sour dirt, sulphur, and lime rock on the surface are indications of the salt dome.

Two hundred ninety-one wells were drilled prior to the year 1924, 85 producing oil, 154 being dry, and the remainder being classed as sulphur tests. Total production for this period amounts to 5,008,870 bbls., all of which was obtained from an area of 280 acres. There are two producing areas, one on the northeastern side, the other on the southwestern side of the dome. The major portion of oil was obtained from the southwestern side. Production per acre averages 19,265 bbls. Average production of producing wells is 58,927 bbls., and the average depth 2,416 feet. The oil is of asphaltic base with gravities averaging about 22.5° B. Production is obtained around the sides of the dome in sands and limes of Oligocene age.

INTRODUCTION

Damon Mound is located on the Abram Darst survey, in northwestern Brazoria County, Texas, near the Fort Bend County line. It is 38 miles southwest of Houston, 9 miles south of Big Creek, and 10 miles northwest of the West Columbia oil field. A branch of the G. H. & S. A. Railroad extends from Rosenberg to Damon City on the mound. Overland travel by automobile from Houston is satisfactory during dry weather, but roads occasionally become impassable in rainy seasons.

HISTORY

Damon Mound was a famous camp site and stronghold of the Karanawa Indians. They recognized the advantages of this natural elevation and established a settlement on its upper portions. Numerous remains such as arrowheads, pottery, stone implements, and burial grounds are evidence of this early settlement. On the western side of the mound the Indians found a bluish-black substance within and about a crater-like formation. It was unlike the surrounding soil, possessed a sour, acid taste, and was always moist. By drinking water which collected in this substance, the Indians discovered that it possessed curative properties. The renown of this "medicine" spread far and wide, attracting others from districts as far as the present state of Oklahoma. The substance referred to is commonly known as "sour dirt," and is an indication of salt-dome formation. It is now being developed and sold as a medicine.

In 1831, Samuel Damon, Sr., located and established a blacksmith-shop at Damon Mound. While in search for building material, he discovered an outcrop of limestone on the eastern slope of the hill. A quarry was established, and for many years this material was used for building purposes, some of it being shipped by rail to Houston. Water invaded the quarry, and it has been idle for many years. The stone is described as a warty, cavernous limestone, and is probably a portion of the cap rock which has reached the surface.

During the growth and development of the community now known as Damon City, numerous shallow wells were sunk in search of domestic water. Much of this water is mineralized, and no two wells appear to contain water of the same composition. Water in a 40-foot well near the hotel is saline, while wells on the southwestern portion of the dome are generally fresh. A 206-foot well drilled by Mr. Mulcahy, south of the central part of the dome, produces strongly sulphuretted water containing little or no salt. A small amount of inflammable gas rises within a few wells on the mound, but the majority contain no gas.

Crystals of pure sulphur are exposed along the sides of gulleys on the northern portion of the hill. They occur in isolated patches or spots, some of the crystals being an inch or more in length. Several such deposits were found on the Wallace, Mays, and Wisdom properties. The sulphur is of secondary origin and has been deposited within crevices and porous formations by ascending vapors or solutions.

Sour dirt occurs on the western side of the hill within a 6-acre tract owned by the Vitalitas Company. The deposit is irregular in shape and largely confined to an area of about 1 acre. The material is bluish black in color, but weathers to a pale yellowish brown on exposure. It is largely composed of siliceous material containing quantities of iron pyrite and marcasite. The whole is impregnated with soluble sulphates and chlorides of iron, aluminum, magnesium, sodium, and calcium, together with a small amount of free sulphuric acid. The deposit is of secondary origin and was probably formed by the reaction of escaping sulphurous gases with water and material of adjacent formations. It is reported that tests of the sour dirt indicate a small amount of radioactive material; however, a sample submitted by the writer to the Radium Chemical Company of Pittsburgh contained no radioactive elements. A chemical analysis of the raw material, made by Dr. E. H. S. Bailey, of the University of Kansas, shows the composition given in Table I. Dr. P. S. Tilson, of the Houston Laboratories, gives an analysis based on 100 per cent of the water-soluble material, as shown in Table II.

INDICATIONS OF SALT-DOME STRUCTURE

Indications of salt-dome structure are numerous and easy to identify at Damon Mound. The most impressive is the high, rounded elevation, which is plainly visible for a distance of 5 or 6 miles. The occurrence of inflammable gas and highly mineralized water in shallow wells, sour dirt, crystallized sulphur, and lime rock on the surface are all regarded as companions of salt-dome formation. Many of these indications were recognized and believed to be associates of salt and oil deposits prior to the discovery of oil in Gulf Coast territory; however, little was known about the nature of salt-dome structure, and it required a well such as the famous Lucas gusher of Spindletop to direct the attention of operators to Damon Mound.

TABLE I

	Per Cent
Silica	59.33
Ferric oxide	22.40
Sulphuric anhydrid	3.07
Sulphur	16.13
Water	1.85

TABLE II

	Per Cent
Iron sulphate, $FeSO_4—7H_2O$	40.003
Aluminum sulphate,—$Al_2—3(4SO_4)—16H_2O$	37.856
Sodium-alum, $2(SO_2)—12(H_2O)$	7.246
Calcium chloride, $2(CaCl_2)—6H_2O$	.736
Calcium sulphate, $CaSO_4—7H_2O$	1.985
Magnesium chloride, $MgCl_2—6H_2O$	1.651
Magnesium sulphate, $MgSO_4—7H_2O$	3.140
Sodium chloride, $NaCl$	2.327
Sodium sulphate, $4(Na_2O)—10H_2O$	5.056

DEVELOPMENT

Mr. J. M. Guffey, prominent in the early development of salt-dome oil fields, was the first to acquire leases at Damon Mound. His initial test, known as the Herndon well, is located on Mulcahy Avenue, Block 3, of the Damon High School addition. The well was completed late in the year 1901 at a depth of 1,160 feet. Rock salt was entered at 587 feet and continued to the bottom. No showings of oil or gas are reported, but this test clearly demonstrated the presence of a salt dome. Two additional wells were drilled by Mr. Guffey at the base of the dome, one on the northern side, the other on the northwestern side. No showings of oil or gas are reported from either well, and it is said that the drills penetrated a series of unconsolidated sands, shales, and clays. A total of five wells were drilled in four years without obtaining a favorable show of oil or gas. Owing to the activity of other fields, Damon Mound was neglected from 1905 to 1914.

Early in the year 1915, Mr. H. T. Staiti and associates organized the Texas Exploration Company, acquiring leases and mineral rights covering a greater portion of the mound. Their initial test, Wisdom No. 1, was located by Mr. E. F. Simms on Block 6 of the Wisdom subdivision, near the western base of the hill. A depth of 1,953 feet was reached after passing through 940 feet of rock salt. During the progress of drilling, a particularly favorable showing of oil and gas appeared in a sandy formation at 650 feet. Before abandoning the location, it was decided to test this horizon. The well came in November 15, 1915, and ran wild for a time, making about 5,000,000 cubic feet of gas and 100 barrels of oil per day. The countryside was covered with oil spray carried by a strong wind for a distance of more than 2,500 feet. After some difficulty the flow was controlled and, owing to insufficient storage, was shut in. It later sanded, and the hole was finally junked in an effort to revive production. The oil has a gravity of 35° Baumé, several hundred barrels of which were collected and used for fuel in drilling other wells. This is the first well to produce oil at Damon Mound, and although not a commercial success, it served to demonstrate the presence of oil and attracted the attention of other operators to this field.

Fifteen wells were drilled in 1915, all of which are reported as failures. Most of these tests are located on top of the hill, the majority being abandoned in salt or gypsum at shallow depths. While drilling on the Wallace and Mays tracts, crystals of sulphur were noted coming up with the returns, and during the following year prospective work was started in an attempt to outline and determine the thickness of these deposits.

The year 1917 was a period of intense activity, seventy-seven wells being drilled, of which ten produced oil, forty-three were dry, and the remainder completed as sulphur tests. Production increased to 69,000 barrels during the month of April, declined rapidly, and again increased to 74,700 barrels in August. The major portion of this increase is due to the completion of two wells, Bryan No. 1 and Bryan No. 3, by the Texas Exploration Company.

Bryan No. 3 is not only the first successful well, but the best well ever obtained at Damon Mound; it came in April 5, 1917, making dry gas, and ran wild for twelve days. Oil then appeared and increased in quantity to about 400 barrels per day, when it sanded. The well was later cleaned and started flowing at the rate of 7,500 barrels per day. Thirty-nine feet of hard, porous, calcareous rock, showing considerable oil and gas, were penetrated from 1,410 to 1,449 feet. No screen was set in this well, and top water was excluded by setting $4\frac{1}{2}$-inch pipe on top of the rock. The oil has a gravity of 24° Baumé with an initial temperature of 90° F.

No. 1 T. H. Bryan was completed June 30, 1917. This well, like Bryan No. 3, came in making dry gas and about 400 barrels of oil. Production, however, increased rapidly, and within a short time was flowing pipe-line oil at the rate of 3,500 barrels per day. Sixty-one feet of 3-inch screen was set at 3,473 feet in sand and shale containing a rich oil show. The oil has a gravity of 20° Baumé and initial temperature of 90° F. Three additional producers completed by the Texas Exploration Company within the year, together with five completions by other operators, gave an additional 2,600 barrels initial production, all of which came from depths of approximately 1,500 feet.

During the latter part of 1917 the Texas Exploration Company transferred all of their holdings, excepting sulphur rights, to the Sinclair Oil and Gas Company. The Sinclair organization assumed immediate control and started an active campaign for the development of oil and gas deposits. The Texas Exploration Company remained in the field finishing wells already started and continuing prospective work for sulphur deposits.

Eighty-five wells were completed during the years 1918–19, of which twenty produced oil, fifty-one were dry, and the remainder drilled as sulphur tests. The Texas Exploration Company's No. 1 Radmohr is the best well of this period. It was completed as a 350-barrel producer at 2,527 feet, but made large quantities of water with the oil. The twenty producing wells gave a combined initial production of 2,269 barrels, most of which came from depths around 1,500 feet. Production declined rapidly, then remained fairly constant at an average of 22,500 barrels per month from January 1, 1918, to May 1, 1920.

The year 1920 is perhaps the most important in the history of Damon Mound development. Nineteen wells were completed, ten of which produced oil, adding a total of 15,560 barrels initial daily production to the field. Production increased rapidly to a maximum of 150,375 barrels during the month of December, which is the greatest production recorded in the history of the field. Three wells of the gusher type were completed by the Sinclair Oil and Gas Company, Bryan Nos. 15 and 16 and Masterson No. 10. The Humble Oil and Refining Company also secured a good well in their No. 2 Gallaher. All of these wells are located on the southwestern flank of the dome.

Bryan No. 15 came in during the latter part of April with an initial flow of 2,500 barrels per day. After cleaning itself, the flow increased to 4,000 barrels, making pipe-line oil containing 0.1 per cent water and basic sediment. The gravity of the oil was 23° Baumé with an initial temperature of 80° F. One hundred and forty-two feet of 4-inch screen was set on bottom at 3,103 feet, including a series of sands and shales with some gumbo and bowlders. Shows of oil were recorded at intervals, with 15 feet of very rich sand at 3,088 to 3,103 feet.

The Humble Oil and Refining Company obtained a 1,000-barrel well in No. 2 Gallaher at 3,213 feet. Three joints of 80-mesh screen was set on bottom. including 90 feet oi sandy shale containing an occasional oily horizon. The well came in September 16, producing 23° gravity oil containing 0.2 per cent basic sediment and water.

The Sinclair Oil and Gas Company's No. 16 Bryan is generally recognized as the second largest well of the field. It was completed September 24, with an initial flow estimated at 5,000 to 6,000 barrels per day. The oil has a gravity of 21° Baumé with initial temperature of 94° F. and contains 0.05 per cent water and basic sediment. One hundred and thirty-six feet of 10-gauge, 4-inch strainer was set on bottom at 2,774 feet. The formations included in this setting are largely composed of alternating sands, shales, and gumbo, containing an occasional show of oil and gas. A hard, sandy rock at 2,693 to 2,712 feet is the principal producing horizon.

Masterson No. 10 was drilled to 3,256 feet and completed December 3, with an initial flow of 5,000 barrels per day. Production is obtained from sandy horizons containing some shale, at 3,133 to 3,152 feet and at 3,185 to 3,205 feet. The oil is of 21° gravity with an initial temperature of 90° F.

Eight producing wells and thirteen dry holes were drilled during the year 1921, the largest well of this group being the Sinclair Oil and Gas Company's No. 18 Bryan, which was completed as a 1,200-barrel producer at 3,213 feet. A very interesting test, known as R Damon No. 1, was made by the Hyde Production Company on the southern edge of the field. While drilling at a depth of 2,670 feet, the well blew out and ran wild from October 2 to 6, producing large quantities of gas and salt water. The derrick and toolhouse were wrecked before the flow sanded. Drilling operations were resumed and the well sidetracked to 3,255 feet in heaving shale. It was then decided to shoot the well and test a sandy horizon showing oil and gas at 3,170 feet. This shot resulted in a second blowout more severe than the first. The derrick and immediate equipment were lost, and the blow lasted for eleven days, throwing out large quantities of gas, salt water, sand, and shale. The well sanded up December 31, 1921, but was completely ruined.

An increase in activity during the year 1922 failed to increase materially the production over that of the previous period, and although a high percentage of wells obtained production, yet it was very evident that the heavy drain upon the producing horizon had decreased the pressure to a point where gusher wells could no longer be expected from further drilling in the old field. An attempt to find new sources of supply by deeper drilling resulted in the majority of wells being abandoned in heaving shale. Other portions of the field to the east and south were tested without obtaining any producer of importance.

During the summer of 1922 the Union Sulphur Company entered the field primarily in search of new sulphur deposits. An option or agreement with the Texas Exploration Company permitted the sulphur company to proceed with a series of test wells. Their first well, located on Block No. 11 of the Wisdom subdivision, was completed October 8, at a depth of 347 feet.

The operations of 1923 were largely a continuation of prospective work in an effort to locate a new pool on the eastern and southern sides of the field. All wells on the southern side of the dome entered heaving shale, and such oil sands as were found did not yield more than 10 to 15 barrels of initial production when tested. Those on the eastern side encountered exceedingly steep dips, and although slightly better results were obtained, the wells were of short life and did not justify the expenditure. The Union Sulphur Company completed a series of nine wells, established a battery of steam boilers, and made an experimental steam test in an effort to determine the commercial value of sulphur deposits at Damon Mound. The result of this test was evidently unsatisfactory, for the Union Sulphur Company abandoned further work and withdrew from the field.

The present (December, 1924) daily production of Damon Mound totals 1,325 barrels, all of which is obtained from fifty-three wells; fifty-one are on the southwestern side and two on the northeastern side. All wells are pumped, and about 32 per cent of the fluid obtained is water. Production has reached a settled stage and is slowly declining.

Development to date has resulted in the discovery of two producing areas located, respectively, on the southwestern and northeastern flanks of the dome. The major portion of oil was produced on the southwestern side, the northeastern side giving wells of low initial production and short life. The combined area of the two fields covers about 260 acres and yielded 5,008,870 barrels of oil prior to the year 1924.

A total of 291 wells were drilled at Damon Mound, 85 of which produced oil 154 were non-productive, and the remaining 52 completed as sulphur tests. Since these sulphur tests are shallow and were drilled solely for the purpose of exploring sulphur deposits, we can separate this work from that of wells drilled for oil.

A summary of the statistics of Damon Mound oil wells shows that the average well came in with an initial production of 466 barrels and produced a total of 58,927 barrels from a depth of 2,416 feet. See Table III.

PHYSIOGRAPHY

Damon Mound is located midway between Brazos and San Bernard rivers, both of which have cut deep channels in an almost featureless prairie. The surrounding country is typical of the Gulf coastal plain and slopes gently toward the Gulf at an average rate of $1\frac{1}{2}$ feet per mile.

The mound is one of the most conspicuous topographic features of the Texas coastal plain, and can be observed from all directions for a distance of many miles. It rises 83 feet above the surrounding prairie to a maximum elevation of 140 feet, the high point being in blocks 13 and 14 of the Wisdom subdivision, 2,700 feet north of the center of the mound. The mound is oval in shape and covers an area of 1,670 acres. The major axis is 12,000 feet long and extends N. 34° W., the minor axis being 8,250 feet at right angles.

Radial drainage lines extend in all directions down the sides of the mound. Erosion has been active, and the surface is unevenly

TABLE III

DEVELOPMENT AT DAMON MOUND

Operator	Tract	Well No.	Date	Initial Production (Barrels)	Depth (Feet)	Remarks
J. M. Guffey	Herndon	1	1901	Dry	1,160	Salt 573–1,160 ft.
J. M. Guffey	Mulcahy	1	1901	Dry	1,097	Abandoned in hard lime
Damon Mound Oil & P. L. Co.	Mulcahy	1	1902	Dry	1,230	Abandoned in sand and clay
J. M. Guffey	Mulcahy	2	1902	Dry	1,380	No data
R. F. Mulcahy	Mulcahy	1	1904	Dry	250	Abandoned in hard rock
Damon Humble Oil Co.	Clark	1	1916	Dry	949	Junked
Damon Humble Oil Co.	Howell	1	1916	Dry	800	Junked
Producers Oil Co.	Howell	1	1916	Dry	3,085	Tested salt water
Texas Exploration Co.	Becker	1	1916	Dry	1,580	Abandoned in blue clay
Texas Exploration Co.	Fordtram	1	1916	Dry	550	Abandoned in salt
Texas Exploration Co.	Mayes	1	1916	Dry	695	Abandoned in salt
Texas Exploration Co.	Mayes	2	1916	Dry	521	Abandoned in gypsum
Texas Exploration Co.	Mulcahy	1	1916	Dry	797	Salt 587–797 ft.
Texas Exploration Co.	Thomas	1	1916	Dry	1,785	No data
Texas Exploration Co.	Wallace	1	1916	Dry	650	Salt 600–50 ft.
Texas Exploration Co.	Wallace	2	1916	Dry	573	Salt 565–73 ft.
Texas Exploration Co.	Wallace	3	1916	Dry	410	Abandoned in gypsum
Texas Exploration Co.	Wisdom	1	1916	100	1,953	Salt 1,000–1,953 ft.
Texas Exploration Co.	Wisdom	2	1916	Dry	986	Junked in hard rock
Texas Exploration Co.	Wisdom	3	1916	Dry	865	Salt 855–65 ft.
Couch *et al.*	Gierson	1	1917	300	1,527	19° gravity oil
Couch *et al.*	Gierson	2	1917	300	1,551	20° gravity oil
Cummings & Wilkerson	Cushing	1	1917	Dry	910	Abandoned in heaving shale
Cummings & Wilkerson	Mulcahy	1	1917	Dry	550	Junked
Damon Humble Oil Co.	Clark	2	1917	Dry	1,030	No data
General Petroleum Co.	Bryan	1	1917	Dry	1,480	Tested salt water
General Petroleum Co.	Bryan	2	1917	Dry	1,400	Junked
Humble Oil & Ref. Co.	Allen	1	1917	Dry	399	Gypsum 393–99 ft.
Humble Oil & Ref. Co.	Allen	2	1917	Dry	1,513	Abandoned in salt

Humble Oil & Ref. Co.	Bryan	1	1917	350	1,487	50 per cent water and basic sediment
Humble Oil & Ref. Co.	Bryan	2	1917	500	1,574	50 per cent water and basic sediment
Humble Oil & Ref. Co.	Bryan	3	1917	Dry	675	
Producers Oil Co.	Cave	1	1917	Dry	385	Gypsum 375–85 ft.
Producers Oil Co.	Cave	2	1917	Dry	547	Salt 540–47 ft.
Producers Oil Co.	Howell	2	1917	Dry	3,530	Show of oil at 1,540 ft.
Success Oil Co.	Lowe	1	1917	Dry	1,737	Tested salt water
Success Oil Co.	Lowe	2	1917	200	1,695	80 per cent water and basic sediment
Swift Oil & Sulphur Co.	Freeman	1	1917	Dry	505	Show of oil at 447 ft.
Tarber Oil Co.	Bryan	1	1917	Dry	1,885	Abandoned in shale
Tarber Oil Co.	Bryan	2	1917	Dry	345	Abandoned in lime rock
Tarber Oil Co.	Hankamer	1	1917	Dry	341	Abandoned in lime rock
Texas Exploration Co.	Becker	2	1917	Dry	3,579	Abandoned in lime rock
Texas Exploration Co.	Bryan, J. L.	1	1917	500	1,557	24° gravity oil—18 per cent water and basic sediment
Texas Exploration Co.	Bryan, T. H.	1	1917	3,500	3,473	20° gravity oil—90° F.
Texas Exploration Co.	Bryan, T. H.	2	1917	Dry	144	Gypsum rock 128–44 ft.
Texas Exploration Co.	Bryan, T. H.	3	1917	7,500	1,449	24° gravity oil
Texas Exploration Co.	Bryan, T. H.	4	1917	250	1,717	24° gravity oil—100° F.
Texas Exploration Co.	Bryan, T. H.	5	1917	Dry	1,723	Junked in rock
Texas Exploration Co.	Cave Heirs	AA-21	1917	Dry	1,080	Abandoned in gumbo and gypsum
Texas Exploration Co.	Cave, Nellie	1	1917	Dry	600	Abandoned in salt
Texas Exploration Co.	Cave, Nellie	2	1917	Dry	583	Abandoned in salt
Texas Exploration Co.	Cave, W. M.	Y-19	1917	Dry	545	Abandoned in gypsum
Texas Exploration Co.	Cave, W. M.	Y-21	1917	Dry	533	Abandoned in gypsum
Texas Exploration Co.	Cave, W. M.	Y-23A	1917	Dry	637	Salt 634–37 ft.
Texas Exploration Co.	Community	1	1917	Dry	555	Salt 550–55 ft.
Texas Exploration Co.	Damon L. Z.	R-18A	1917	Dry	525	Abandoned in gypsum
Texas Exploration Co.	Damon, M.	1	1917	Dry	1,841	Junked in rock
Texas Exploration Co.	Damon, M.	2	1917	200	1,710	19° gravity oil—4 per cent water and basic sediment
Texas Exploration Co.	Damon, M.	3	1917	Dry	1,720	Tested salt water
Texas Exploration Co.	Farrell	1	1917	Dry	2,022	Abandoned in gypsum
Texas Exploration Co.	Gulf Smith	1	1917	Dry	2,026	Heaving shale 1,966–2,026 ft.
Texas Exploration Co.	Gulf Smith	1A	1917	Dry	1,919	Junked in sand rock
Texas Exploration Co.	Masterson	1	1917	Dry	1,548	Tested salt water
Texas Exploration Co.	Mayes	R-24-A	1917	Dry	545	Salt 535–45 ft.

TABLE III—*Continued*

Operator	Tract	Well No.	Date	Initial Production (Barrels)	Depth (Feet)	Remarks
Texas Exploration Co.	Mayes	R-24-B	1917	Dry	554	Salt 553–54 ft.
Texas Exploration Co.	Mayes	R-25-A	1917	Dry	537	Salt 536–37 ft.
Texas Exploration Co.	Mayes	S-24-A	1917	Dry	477	Abandoned in gypsum
Texas Exploration Co.	Mayes	W-19	1917	Dry	475	Abandoned in gypsum
Texas Exploration Co.	Mayes	W-24-A	1917	Dry	546	Salt 544–46 ft.
Texas Exploration Co.	Mulcahy	2	1917	Dry	592	Salt 591–92 ft.
Texas Exploration Co.	Mulcahy	3	1917	Dry	584	Salt 579–84 ft.
Texas Exploration Co.	Mulcahy	4	1917	Dry	449	Abandoned in gypsum
Texas Exploration Co.	Mulcahy	5	1917	Dry	583	Salt 580–83 ft.
Texas Exploration Co.	Mulcahy	6	1917	Dry	578	Salt 564–78 ft.
Texas Exploration Co.	Mulcahy	7	1917	Dry	572	Salt 570–72 ft.
Texas Exploration Co.	Mulcahy	8	1917	Dry	561	Salt 551–61 ft.
Texas Exploration Co.	Mulcahy	9	1917	Dry	551	Salt 548–51 ft.
Texas Exploration Co.	Munson	1	1917	Dry	3,440	Abandoned in heaving shale
Texas Exploration Co.	Munson	2	1917	Dry	3,448	Abandoned in salt
Texas Exploration Co.	Thomas	1	1917	Dry	1,785	No data
Texas Exploration Co.	Wallace	O-21	1917	Dry	580	Salt 536–80 ft.
Texas Exploration Co.	Wallace	R-21A	1917	Dry	558	Salt 556–58 ft.
Texas Exploration Co.	Wallace	S-21A	1917	Dry	536	Abandoned in gypsum
Texas Exploration Co.	Wallace	4	1917	Dry	408	Abandoned in gypsum
Texas Exploration Co.	Wallace	5	1917	Dry	550	Abandoned in gypsum
Texas Exploration Co.	Wallace	6	1917	Dry	605	Abandoned in salt
Texas Exploration Co.	Wallace	7	1917	Dry	600	Abandoned in salt
Texas Exploration Co.	Wallace	8	1917	Dry	600	Abandoned in salt
Texas Exploration Co.	Wallace	9	1917	Dry	600	Abandoned in salt
Texas Exploration Co.	Wallace	10	1917	Dry	600	Abandoned in salt
Texas Exploration Co.	Wisdom	4	1917	Dry	1,514	Junked
Texas Exploration Co.	Wisdom	4A	1917	Dry	1,459	Salt 1,416–59 ft.
Texas Exploration Co.	Wisdom	5	1917	Dry	3,529	Junked in hard sand
Texas Exploration Co.	Wisdom	6	1917	Dry	558	Salt 553–58 ft.

Texas Exploration Co.	Woodward	1	1917	Dry	1,560	Tested salt water
Texas Exploration Co.	Woodward	2	1917	Dry	1,445	Junked in hard rock
Webber & Andegree	Lucas	1	1917	Dry	1,045	Little dry gas
Adams Oil Association	Tarleton	1	1918	Dry	1,019	
Atkinson Oil Co.	Bryan	1	1918	25	1,420	
Atkinson Oil Co.	Bryan	2	1918	Dry	1,500	Tested salt water
Cummings & Wilkerson	Mulcahy	2	1918	Dry	915	Abandoned in heaving shale
Cummings & Wilkerson	Mulcahy	3	1918	Dry	717	Abandoned in heaving shale
Denver Oil Co.	Bryan	1	1918	Dry	2,208	Abandoned in hard rock
General Petroleum Co.	Bryan	4	1918	10	1,590	Flooded by salt water
General Petroleum Co.	Lockwood	1	1918	Dry	3,051	No data
Glen Petroleum Co.	Centex	1	1918	Dry	2,210	Junked
Gulf Prod. Co.	Robertson	1	1918	57	1,600	
Gulf Prod. Co.	Robertson	2	1918	Dry	1,628	Junked in hard rock
Humble Oil & Ref. Co.	Bryan	3A	1918	Dry	680	Junked in hard rock
Humble Oil & Ref. Co.	Bryan	3B	1918	Dry	512	Junked in hard rock
Humble Oil & Ref. Co.	Bryan	3C	1918	Dry	1,502	Tested salt water
Humble Oil & Ref. Co.	Bryan	4	1918	225	1,527	10 per cent water and basic sediment
Humble Oil & Ref. Co.	Bryan	5	1918	22	1,573	
Humble Oil & Ref. Co.	Gallaher	1	1918	Dry	3,247	Tested salt water
Hyde Prod. Co.	Bryan	1	1918	Dry	1,664	Tested salt water
Mankers Oil & Ref. Co.	Bryan	1	1918	40	1,525	Flooded by salt water
Royal Oil & Ref. Co.	Bryan	1	1918	25	1,450	5 per cent water and basic sediment
Royal Oil & Ref. Co.	Bryan	2	1918	30	1,534	
Sinclair Oil & Gas Co.	Bryan	1	1918	50	1,580	
Sinclair Oil & Gas Co.	Masterson	6	1918	10	2,085	Production at 1,448 ft.
Sinclair Oil & Gas Co.	Norton	1	1918	Dry	4,229	Abandoned in sand and shale
Sinclair Oil & Gas Co.	Ptak	1	1918	Dry	4,625	Little 25° gravity oil
Sinclair Oil & Gas Co.	Thomas	2	1918	Dry	3,280	Little oil at 3,152 ft.
Sinclair Oil & Gas Co.	Wisdom	7	1918	Dry	2,422	Junked in hard sand
Success Oil Co.	Hillyer	1	1918	Dry	2,835	Tested salt water
Success Oil Co.	Lowe	3	1918	Dry	1,735	Tested salt water
Swift Oil & Sulphur Co.	Freeman	2	1918	Dry	634	
Swift Oil & Sulphur Co.	Freeman	3	1918	Dry	700	Salt 618–700 ft.
Swift Oil & Sulphur Co.	Horn	1	1918	Dry	2,600	

TABLE III—*Continued*

Operator	Tract	Well No.	Date	Initial Production (Barrels)	Depth (Feet)	Remarks
Swift Oil & Sulphur Co.	Jackson	1	1918	Dry	2,237	Abandoned in rock
Texas Co.	Munson	1	1918	Dry	3,462	Little oil at 2,650 ft.
Texas Co.	Munson	2	1918	Dry	3,452	Abandoned in salt
Texas Exploration Co.	Becker	2	1918	Dry	3,566	Abandoned in lime rock
Texas Exploration Co.	Bryan	6	1918	225	2,493	Pipe-line oil
Texas Exploration Co.	Bryan	7	1918	Dry	1,640	Tested dry
Texas Exploration Co.	Bryan	8	1918	Dry	3,591	Abandoned in heaving shale
Texas Exploration Co.	Bryan	9	1918	Dry	2,308	
Texas Exploration Co.	Cave	X-23A	1918	Dry	548	Salt 545–48 ft.
Texas Exploration Co.	Cave	X-24A	1918	Dry	525	Abandoned in gypsum
Texas Exploration Co.	Damon, L. Z.	1	1918	Dry	1,841	Junked
Texas Exploration Co.	Damon, M	4	1918	200	2,490	
Texas Exploration Co.	Damon, M.	5	1918	Dry	1,588	
Texas Exploration Co.	Jackson	5	1918	Dry	2,093	Show of oil at 2,087 ft.
Texas Exploration Co.	Jackson	6	1918	Dry	742	Tested salt water
Texas Exploration Co.	Masterson	1	1918	Dry	681	Abandoned in salt
Texas Exploration Co.	Masterson	2	1918	Dry	2,453	Junked
Texas Exploration Co.	Masterson	3	1918	200	1,358	Heavy gas pressure
Texas Exploration Co.	Masterson	4	1918	300	1,667	
Texas Exploration Co.	Mayes	V-22A	1918	Dry	529	Abandoned in gypsum
Texas Exploration Co.	Mayes	W-22A	1918	Dry	562	Salt 560–62 ft.
Texas Exploration Co.	Mulcahy	10	1918	Dry	551	Salt 548–51 ft.
Texas Exploration Co.	Mulcahy	11	1918	Dry	579	Salt 577–79 ft.
Texas Exploration Co.	Ramdohr	1	1918	350	2,527	95 per cent water and basic sediment
Texas Exploration Co.	Wisdom	5A	1918	Dry	1,057	Junked
Texas Exploration Co.	Wisdom	O-22A	1918	Dry	775	Abandoned in salt
Texas Exploration Co.	Wisdom	O-23A	1918	Dry	546	Salt 544–46 ft.
Texas Exploration Co.	Wisdom	O-24A	1918	Dry	530	Salt 527–30 ft.
Texas Exploration Co.	Wisdom	O-24B	1918	Dry	530	Salt 529–30 ft.
Texas Exploration Co.	Wisdom	P-25A	1918	Dry	538	Salt 536–38 ft.

Texas Exploration Co.	Wisdom	S-24B	1918	Dry	562	Salt 561–62 ft.
Texas Exploration Co.	Wisdom	S-25A	1918	Dry	546	Salt 544–46 ft.
Texas Exploration Co.	Wisdom	T-25A	1918	Dry	545	Salt 544–45 ft.
Texas Exploration Co.	Woodward	3	1918	120	1,558	9 per cent water and basic sediment
Webber & Andegree	Lucas	2	1918	50	1,645	
Webber & Andegree	Lucas	3	1918	Dry	1,625	Junked
Sinclair Oil & Gas Co.	Becker	3	1919	Dry	3,435	Sand rock, show of light oil
Sinclair Oil & Gas Co.	Bryan	10	1919	Dry	2,835	
Sinclair Oil & Gas Co.	Bryan	12	1919	Dry	1,734	Junked in lime rock
Sinclair Oil & Gas Co.	Bryan	13	1919	Dry	1,728	Junked in lime rock
Sinclair Oil & Gas Co.	Jackson	8	1919	Dry	2,072	Abandoned in heaving shale
Sinclair Oil & Gas Co.	Jackson	9	1919	100	1,529	19 ft. of hard oil sand
Sinclair Oil & Gas Co.	Kempner	1	1919	Dry	1,810	Salt 1,800–10 ft.
Sinclair Oil & Gas Co.	Masterson	7	1919	Dry	2,423	Junked
Sinclair Oil & Gas Co.	Masterson, N. T.	1	1919	Dry	2,410	
Sinclair Oil & Gas Co.	Masterson (trustee)	1	1919	150	2,298	Production at 1,640 ft.
Sinclair Oil & Gas Co.	Mayes	3	1919	Dry	3,022	Junked in hard rock
Sinclair Oil & Gas Co.	Norton	1	1919	Dry	4,229	Junked—show of oil 4,024 ft.
Sinclair Oil & Gas Co.	Sinclair (fee)	1	1919	Dry	1,358	
Sinclair Oil & Gas Co.	Thomas	3	1919	80	1,780	
Sinclair Oil & Gas Co.	Wisdom	8	1919	Dry	3,370	Tested salt water
Sinclair Oil & Gas Co	Wisdom	9	1919	Dry	1,584	Salt 1,579–84 ft.
Sinclair Oil & Gas Co.	Woodward	4	1919	Dry	2,027	Abandoned in salt
Humble Oil & Ref. Co.	Gallaher	2	1920	1,000	3,212	23° gravity oil
Humble Oil & Ref. Co.	Gallaher	3	1920	Dry	3,480	Salt 3,474–80 ft.
Sinclair Oil & Gas Co.	Becker	4	1920	Dry	1,960	Abandoned in salty shale
Sinclair Oil & Gas Co.	Bryan	14	1920	Dry	2,525	Show of oil at 2,450 ft.
Sinclair Oil & Gas Co.	Bryan	15	1920	4,000	3,103	23° gravity oil—80° F.
Sinclair Oil & Gas Co.	Bryan	16	1920	5,000	2,774	22.4° gravity oil—94° F.
Sinclair Oil & Gas Co.	Bryan	17	1920	Dry	2,631	Junked
Sinclair Oil & Gas Co.	Bryan	19	1920	Dry	2,330	Abandoned in shale
Sinclair Oil & Gas Co.	Duncan	1	1920	125	1,454	
Sinclair Oil & Gas Co.	Jackson	10	1920	Dry	1,574	Tested salt water

TABLE III—*Continued*

Operator	Tract	Well No.	Date	Initial Production (Barrels)	Depth (Feet)	Remarks
Sinclair Oil & Gas Co.	Jackson	11	1920	120	1,812	20° gravity oil—85° F.
Sinclair Oil & Gas Co.	Masterson	8	1920	30	2,786	
Sinclair Oil & Gas Co.	Masterson	9	1920	10	1,542	Production at 1,350 ft.
Sinclair Oil & Gas Co.	Masterson	10	1920	5,000	3,256	21° gravity oil
Sinclair Oil & Gas Co.	Munson	1	1920	50	3,116	Flooded by salt water
Sinclair Oil & Gas Co.	Norton	2	1920	Dry	1,210	Junked
Sinclair Oil & Gas Co.	Ptak	2	1920	Dry	4,650	
Sinclair Oil & Gas Co.	Sinclair (fee)	1A	1920	Dry	2,134	
Sinclair Oil & Gas Co.	Thomas	4	1920	225	1,604	
Humble Oil & Ref. Co.	Damon	1	1921	Dry	468	Abandoned in gravel
Humble Oil & Ref. Co.	Gallaher	4	1921	Dry	3,758	
Humble Oil & Ref. Co.	Gallaher	5	1921	100	2,860	
Humble Oil & Ref. Co.	Kitchen	1	1921	Dry	4,540	Abandoned in heaving shale
Humble Oil & Ref. Co.	Mock	1	1921	Dry	3,553	Show of light oil
Hyde Prod. Co.	Damon, R.	1	1921	Dry	3,255	Abandoned in heaving shale
Oil Producers Co.	Damon, L. Z.	1	1921	Dry	2,410	Abandoned in gypsum
Poor Boy Oil Co.	Bellville	1	1921	Dry	2,940	Abandoned in heaving shale
Sinclair Oil & Gas Co.	Bryan	17A	1921	Dry	2,625	
Sinclair Oil & Gas Co.	Bryan	18	1921	1,200	3,213	
Sinclair Oil & Gas Co.	Bryan	20	1921	Dry	3,377	Tested salt water
Sinclair Oil & Gas Co.	Bryan	21	1921	100	2,457	
Sinclair Oil & Gas Co.	Cummings	1	1921	Dry	2,550	Show of light oil
Sinclair Oil & Gas Co.	Masterson, N. T.	2	1921	Dry	2,087	Tested salt water
Sinclair Oil & Gas Co.	Masterson (trustee)	2	1921	500	1,700	
Sinclair Oil & Gas Co.	Robertson	1	1921	100	1,618	
Sinclair Oil & Gas Co.	Thomas	5	1921	50	3,280	
Sinclair Oil & Gas Co.	Williams	1	1921	100	1,762	
Southern Petroleum Co.	Bryan	1	1921	500	3,341	
Southern Petroleum Co.	Bryan	2	1921	Dry	3,108	Junked in rock
Southern Petroleum Co.	Norton	1	1921	Dry	3,625	Abandoned in heaving shale
Cullen Syndicate	Ward	1	1922	Dry	3,245	Abandoned in heaving shale

Cullen Syndicate	Ward	2	1922	Dry	3,355	Abandoned in heaving shale
Hyde Prod. Co	Gibson	1	1922	400	2,992	Pipe-line oil
Hyde Prod. Co	Gibson	2	1922	100	3,068	Production at 2,941 ft.
Hyde Prod. Co	Hillyer	1	1922	Dry	3,650	Heaving shale 3,618–50 ft.
Hyde Prod. Co	Kittrell	1	1922	125	3,170	21° gravity oil
Hyde Prod. Co	Kittrell	2	1922	Dry	3,184	Abandoned in black shale
Hyde Prod. Co	Lockwood	1	1922	Dry	4,014	Abandoned in hard sand
Hyde Prod. Co	Damon, R.	2	1922	Dry	3,823	Heaving shale 3,539–3,823 ft.
Hyde Prod. Co	Wisdom	1	1922	200	3,828	
Sinclair Oil & Gas Co	Bryan	22	1922	50	2,998	
Sinclair Oil & Gas Co	Bryan	23	1922	Dry	2,768	Junked
Sinclair Oil & Gas Co	Bryan	24	1922	150	3,414	
Sinclair Oil & Gas Co	Bryan	25	1922	150	3,055	
Sinclair Oil & Gas Co	Bryan	26	1922	Dry	3,313	Abandoned in heaving shale
Sinclair Oil & Gas Co	Bryan	27	1922	50	3,566	Production at 3,230 ft.
Sinclair Oil & Gas Co	Jackson	12	1922	200	2,983	
Sinclair Oil & Gas Co	Jackson	13	1922	80	1,950	
Sinclair Oil & Gas Co	Jackson	14	1922	Dry	3,492	Abandoned in heaving shale
Sinclair Oil & Gas Co	Lockwood	1	1922	Dry	3,790	Abandoned in heaving shale
Sinclair Oil & Gas Co	Masterson	11	1922	400	3,263	
Sinclair Oil & Gas Co	Masterson	12	1922	50	3,445	
Sinclair Oil & Gas Co	Masterson	13	1922	5	2,628	
Sinclair Oil & Gas Co	Masterson	14	1922	75	1,578	
Sinclair Oil & Gas Co	Masterson	15	1922	50	2,762	
Sinclair Oil & Gas Co	Masterson	16	1922	100	3,113	
Sinclair Oil & Gas Co	Masterson (trustee)	3	1922	100	2,012	
Sinclair Oil & Gas Co	Mock	1	1922	125	3,116	
Sinclair Oil & Gas Co	Munson	2	1922	Dry	3,524	Abandoned in heaving shale
Sinclair Oil & Gas Co	Williams	2	1922	Dry	2,253	Tested salt water
Sinclair Oil & Gas Co	Williams	3	1922	750	3,106	
Sinclair Oil & Gas Co	Williams	4	1922	100	2,995	Heaving shale at bottom
Sinclair Oil & Gas Co	Williams	5	1922	100	2,955	
Sinclair Oil & Gas Co	Williams	6	1922	15	3,252	Flooded by salt water
Sinclair Oil & Gas Co	Williams	7	1922	Dry	3,007	Abandoned in heaving shale
Southern Petroleum Co	Bryan	3	1922	500	3,458	
Southern Petroleum Co	Bryan	4	1922	Dry	3,175	Junked
Southern Petroleum Co	Bryan	5	1922	500	3,443	

TABLE III—*Continued*

Operator	Tract	Well No.	Date	Initial Production (Barrels)	Depth (Feet)	Remarks
Southern Petroleum Co.	Japhet	1	1922	Dry	4,046	Abandoned in heaving shale
Union Sulphur Co.	Wallace	1	1922	Dry	347	Abandoned in gypsum
Union Sulphur Co.	Mayes	1	1922	Dry	499	Abandoned in rock
Union Sulphur Co.	Texas Ex. Co. (fee)	1	1922	Dry	509	Abandoned in gypsum
Union Sulphur Co.	Texas Ex. Co. (fee)	2	1922	Dry	574	Salt 567–74 ft.
Cullen Syndicate	Ward	3	1923	Dry	3,775	Abandoned in heaving shale
Hyde Prod. Co.	Atlantic	1	1923	80	3,528	Abandoned in heaving shale
Hyde Prod. Co.	Atlantic	2	1923	Dry	3,750	Heaving shale 3,680–3,750 ft.
Sinclair Oil & Gas Co.	Becker	5	1923	15	3,058	Abandoned in heaving shale
Sinclair Oil & Gas Co.	Becker	6	1923	10	2,934	Heaving shale—production at 2,430 ft.
Sinclair Oil & Gas Co.	Becker	7	1923	Dry	3,340	Salt 2,955–3,340 ft.
Sinclair Oil & Gas Co.	Becker	8	1923	Dry	3,189	Abandoned in heaving shale
Sinclair Oil & Gas Co.	Bryan	28	1923	30	2,438	
Sinclair Oil & Gas Co.	Bryan	29	1923	30	2,245	
Sinclair Oil & Gas Co.	Jackson	15	1923	100	2,907	
Sinclair Oil & Gas Co.	Jackson	16	1923	Dry	2,425	Junked in lime rock
Sinclair Oil & Gas Co.	Jackson	17	1923	Dry	3,883	
Sinclair Oil & Gas Co.	Jackson	18	1923	5–10	3,814	
Sinclair Oil & Gas Co.	Jackson	19	1923	Dry	3,127	Junked in lime rock
Sinclair Oil & Gas Co.	Jackson	20	1923	150	3,333	35° gravity oil
Sinclair Oil & Gas Co.	Masterson	17	1923	175	1,676	
Sinclair Oil & Gas Co.	Masterson	18	1923	75	1,745	
Sinclair Oil & Gas Co.	Mock	2	1923	250	3,590	
Sinclair Oil & Gas Co.	Mock	3	1923	100	3,416	
Sinclair Oil & Gas Co.	Proctor	1	1923	Dry	1,240	
Southern Petroleum Co.	Norton	2	1923	Dry	3,770	Tested salt water
Union Sulphur Co.	Texas Ex. Co.	3	1923	Dry	544	Abandoned in salt
Union Sulphur Co.	Mayes	2	1923	Dry	551	Salt 546–51 ft.
Union Sulphur Co.	Texas Ex. Co.	4	1923	Dry	668	Salt 648–68 ft.
Union Sulphur Co.	Wisdom	1	1923	Dry	745	Abandoned in gypsum
Union Sulphur Co.	Jackson	1	1923	Dry	528	Abandoned in gypsum

eroded into little hills or hummocks. The present topography, while corresponding in outline with the core of the dome, has no apparent relationship to the detail of subsurface structure. (Fig. 1.)

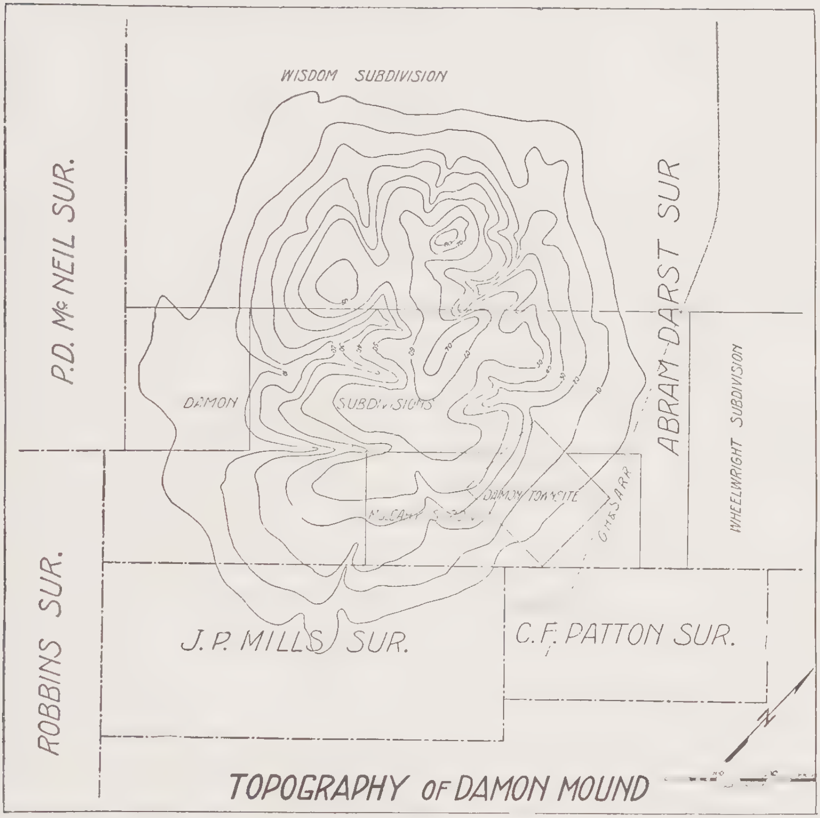


FIG. 1

GEOLOGY

Surface exposures are largely composed of red, blue, brown, and yellow clays with some sand and a little shale. The clays are calcareous and contain occasional limy concretions which weather out and collect in the bottom of drainage lines. The exposed formations are evidently a portion of the Beaumont clay, although some gravel was noted on the eastern side of the mound which has the appearance of Lissie gravel. Surface formations are unconsolidated and apparently lie in a horizontal position, but do not display bedding-planes or other visible characteristics which could be used to determine the presence of structural deformation.

Subsurface conditions show the presence of an intrusive salt core capped by deposits of gypsum, anhydrite, and limestone. Adjacent formations are inclined at a steep angle sloping in all directions away from the salt.

SALT CORE

The upper extremity of the salt core is somewhat oval in outline, being essentially flat with rounded edges dipping to an unknown depth at an angle of about 83°. On the southwestern edge of the dome, immediately south of the oil field, there is an outlier of salt which extends beyond the generally symmetrical outline of the salt core. This outlier is probably an arm of salt which was squeezed out by unequal pressure. Core samples show that the salt plug is composed of almost pure rock salt containing waves and bands of darker material, indicating that flowage and adjustment has taken place under heavy pressure.

Forty-five wells have entered rock salt, the majority being shallow tests on top of the dome that only penetrated a few feet of this material. The greatest thickness of salt is shown in the Texas Exploration Company's No. 1 Wisdom from 1,000 to 1,953 feet. A sulphur test, O-24A, drilled by the Texas Exploration Company on the northwestern side of the dome, 4,500 feet from the center of the mound, shows the highest portion of salt so far recorded by any test in this field.

CAP ROCK

Cap rock is a term generally applied to mineralized deposits adjacent to and above the salt plug. These deposits are largely composed of gypsum, anhydrite, and limestone, varying in thickness in the central area from 375 to 575 feet, but thinning at the outer edges of the dome to a few feet. They are extremely irregular and occur rather as lenses, pockets, and concretions, no two sections being alike. There is, however, a general arrangement in which the major portion of deposits occur, in the order of gypsum below, limestone at the top, with anhydrite between the two. The cap rock is generally porous and cavernous, containing variable amounts of sulphur, pyrite, calcite, and barite deposited in crystal form throughout the porous spaces. Some of the crystals have rounded edges, while others, particularly the calcite crystals, may be badly corroded, showing the effects of circulating underground waters. The upper portion of the cap rock is composed of hard limy material and is virtually a limestone, although inclusions of gypsum and anhydrite have been noted, together with an occasional thin parting of gumbo. Its thickness varies from 10 to 150 feet, but generally it does not occur as a solid mass. Well records show that the cap rock rises to within 68 feet of the surface, and it is believed that a portion of the cap rock may have extended to the surface on the eastern side of the mound, where limestone similar to cap rock was quarried and used for building purposes.

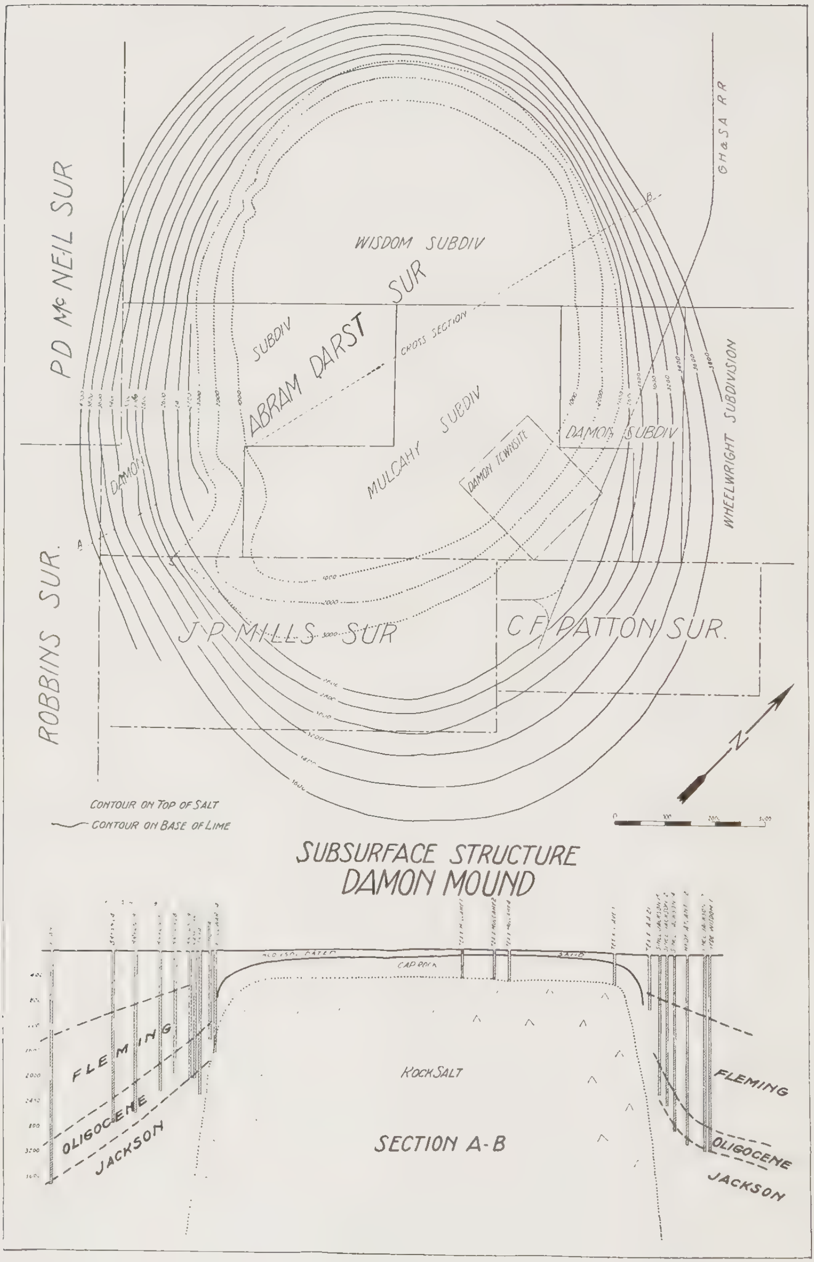
The log of a sulphur test shown in Table IV gives a good description of the cap rock.

STRUCTURE OF SURROUNDING SEDIMENTS

Eighteen hundred feet of structural displacement has been measured, and it is very probable that an additional amount can be proven by further deep drilling. Contour lines, as shown on Figure 2, represent the base of a limestone bed within the *Heterostegina* zone of the Oligocene formation. It furnishes an excellent key horizon for correlation purposes, and has been identified at many points around the major portion of the dome.

The sands within the producing area dip at an angle of about 40°, while formations on the opposite side, to the northeast, dip at a steeper angle, averaging about 60°. Dips of 23° have been recorded on the south, while those to the north approximate 47°.

Faulting.—Faulting is present, generally in the form of step faults extending along lines parallel to the circumference of the dome, the downthrow side being directionally away from the dome. Radial faulting has been noted, particularly in the southwestern flank, south of the old producing area. The presence of faulting can be identified, but owing to the extremely complicated structural conditions, in which radical changes occur within narrow limits, it is


GH & SA RR
B
WISDOM SUBDIV
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ABRAM DARST
SUBDIV
CROSS SECTION
MULCAHY SUBDIV
DAMON TOWNSITE
DAMON SUBDIV
WHEELWRIGHT SUBDIVISION
DAMON
A
ROBBINS SUR.
J P MILLS SUR
C F PATTON SUR.
N
CONTOUR ON TOP OF SALT
CONTOUR ON BASE OF LIME
SUBSURFACE STRUCTURE
DAMON MOUND
CAP ROCK
ROCK SALT
FLEMING
OLIGOCENE
JACKSON
SECTION A-B
FLEMING
OLIGOCENE
JACKSON

FIG. 2

TABLE IV

Texas Exploration Company Well No. R-24b

Depth (Feet)	Formation
22	Sand
48	Yellow clay
67	Yellow clay, gravel, and blue gumbo
68	Limerock
80	Gypsum and limerock, lost returns at 72 feet
85	Limerock, losing returns
88	Sandy gypsum
101	Limerock, lost returns
106	Limerock and gypsum
116	Limerock
135	Lime and pyrite
170	Limerock, trace of sulphur
171	Blue gumbo
173	Limerock
178	Blue gumbo
181	Limerock
185	Shale and gypsum, trace of sulphur
192	Limerock, trace of sulphur
195	Limerock and pyrites
206	Broken limerock
209	Limerock and pyrites
220	Limerock and pyrites, trace of sulphur
235	Broken gypsum
245	Gypsum, very good showing of sulphur
254	Gypsum, 3 per cent of sulphur
260	Gypsum and anhydrite, 5 per cent sulphur
265	Gypsum and anhydrite, 10 per cent sulphur
270	Gypsum and anhydrite, 20 per cent sulphur
275	Gypsum and anhydrite, 15 per cent sulphur
280	Gypsum and anhydrite, 15 per cent sulphur
284	Gypsum and anhydrite, 15 per cent sulphur
297	Gypsum and anhydrite, 3 per cent sulphur
301	Gypsum and anhydrite, 2 per cent sulphur
310	Gypsum, anhydrite, and good showing of sulphur
315	Gypsum and sulphur, 1 foot will run 15 per cent and the rest a good trace
325	Gypsum with good showing of sulphur
343	Gypsum with trace of sulphur
345	Gypsum and sulphur showing
355	Gypsum and sulphur 5 per cent

TABLE IV—*Continued*

Depth (Feet)	Formation
365	Gypsum and sulphur showing
391	Gypsum and sulphur 2 per cent
405	Gypsum and trace of sulphur
455	Smooth gypsum and trace of sulphur
463	Smooth gypsum
479	Compact gypsum
484	Gypsum some transparent
513	Compact gypsum
534	Cavity
535–36	Gypsum, 50 per cent sulphur, loose formation
542	Sidetracked after twisted off
543	Loose formation, sulphur
552	Cavity
553	Gypsum, 50 per cent sulphur
554	Salt

difficult to define any particular fault or zone of faulting with accuracy. Crushed and shattered zones are present usually at the point of contact between the salt plug and surrounding sediments, indicating that considerable movement has taken place under heavy pressure. Wells in this zone are extremely variable, difficult to drill, and usually unproductive.

Faulting at Damon Mound is the result of displacement, induced by an upthrust from below. The force is believed to have been applied gradually over an extended period of time, creating faults at a comparatively slow rate, and not as sudden movement or slippage. Core samples from the faulted zone do not indicate the effect of heat such as would be expected were the fault created by sudden movement.

Heaving shale.—Heaving shale is a term applied to shaly material which rises or heaves within a drilling well. It occurs at many points adjacent to and surrounding the dome, but occasionally rises within faulted areas or paths of least resistance above its normal position. The shale is black to dark gray in color and usually belongs to the Jackson formation; however, some instances have been noted where shales of Oligocene age heaved in a similar manner, and it is believed that any material of shaly nature, regardless of age, will heave when subjected to heavy pressure.

STRATIGRAPHY

Lateral beds surrounding the dome are divided, for convenience of description, into the Jackson, Oligocene, Fleming, and overlying sediments.

Jackson.—Deposits of Jackson age are largely composed of dark-colored shales and clays with an occasional sandy member. The shales heave badly within a drilling well, and for this reason are frequently referred to as "heaving shale." They are somewhat carbonaceous and contain an occasional show of oil and gas, but do not produce in commercial quantities at Damon Mound. The top of the Jackson dips away from the dome at an angle of about 45°. In the Sinclair Oil and Gas Company's Becker No. 7, 559 feet of Jackson material is recorded, this figure representing about 410 feet of actual Jackson formation.

Oligocene.—The Oligocene is divided into three portions, described in the order of their deposition, as the *Marginulina*, *Heterostegina*, and *Discorbis* zones. They represent the Middle and Lower Oligocene, the Upper Oligocene being absent or eroded before the deposition of Fleming sediments. These deposits consist largely of limestones, shales, sands, and clays, representing a thickness of 560 feet near the dome and 750 feet at the outer edges of the field. The base of the Oligocene dips at an angle of about 45°. The Oligocene supplies the major portion of oil produced at Damon Mound. The *Heterostegina* and *Marginulina* zones are particularly rich in petroleum deposits.

Fleming.—The Fleming formation rests unconformably upon the Oligocene. It embraces the Miocene and a portion of the Pliocene formations, and is composed of calcareous clays with concretions, sands, and shales. The thickness varies from 1,000 feet near the dome to 1,750 feet at the outer edges of the field. The base of the Fleming slopes away from the salt plug at an angle of about 40°. Shows of oil and gas occur within its lower portions, and some oil was produced from this horizon on the southwestern side of the dome.

Overlying sediments.—Sediments overlying the Fleming and extending to the surface are of Pleistocene and Pliocene age. They consist in part of fluvatile and shallow-water deposits, comprising a series of sands, gravels, and clays containing an occasional log or bit of buried driftwood. These deposits are lenticular and extremely variable as to character. The thickness averages about 1,400 feet, and the base of the formation dips at an angle of about 15°.

GEOLOGIC HISTORY

The maximum structural displacement occurred at or about the transitional period between the Pliocene-Miocene deposition, and continued with decreasing intensity to the time of Beaumont City deposition. Evidence of movement is indicated during Miocene times and possibly at an earlier period. A small amount of readjustment is believed to be taking place at the present time, for the reason that in 1921 a group of five wells on the Masterson tract suddenly quit producing on account of collapsed casing. No observations have been made to establish the possibility of present-day growth.

ORIGIN OF THE DOME

Damon Mound, although differing in some of its details, is nevertheless a typical salt dome similar to many others of its type. It was formed at about the same time and displays many of the characteristics common to other salt domes of the Gulf Coast district. Its origin is a subject upon which we may draw certain conclusions from conditions believed to exist at great depths. Several theories have been advanced, and since the writer has not observed any conclusive evidence which would add to our present knowledge of salt-dome origin, he therefore refers the reader to discussions already published by students of this subject.

ORIGIN OF THE CAP ROCK

The Damon Mound salt dome penetrates intrusively the surrounding formations. These formations have been cut or broken, permitting an intimate association of included waters with the salt plug. The water is under a static head, subject to minor movements of the dome, and has no doubt dissolved and redistributed a portion of the soluble material according to locally varying conditions and the laws of solubility. In view of the above, it is believed that the mineralized material, such as gypsum, anhydrite, cap rock, sulphur, etc., above the salt is derived from solutions as a precipitate deposition or replacement, and that the character and extent of this material is governed by local conditions and subsequent movements of the dome. The presence of faulting within the cap rock indicates that movement must have taken place after the cap rock was formed.

OIL DEPOSITS

The productive area at Damon Mound is distributed as shown on Plate 10, and represents about 15.5 per cent of the total area of the mound. The oil is believed to originate within bituminous shales of the Jackson, Oligocene, and Miocene formations, and to have later migrated into adjacent sandy horizons. The majority of the so-called oil sands are really admixtures of sand, shale, and clay, divided by partings of clay. They are lenticular, extremely variable as to character, and frequently change within narrow limits. Faulting is believed to play an important rôle in the accumulation of oil, and probably serves as an effectual barrier, retaining the oil on the downthrow side.

The character of oil varies according to location. Heavy oil of asphaltic base and a consistency almost like that of tar is reported to occur in the upper portions of the cap rock and in sands adjacent to the cap rock. Oil of 35° Baumé was produced from a depth of 650 feet in the Texas Exploration Company's No. 1 Wisdom on the western side of the mound. The Sinclair Oil and Gas Company obtained several hundred barrels of 34.5° Baumé oil, containing both paraffin and asphalt, at 3,334 feet in their No. 20 Jackson, 2,500 feet south of the Wisdom well.

Variations of gravity in the old producing area, on the southwestern side of the dome, range from 19° Baumé in the Texas Exploration Company's No. 1 Gierson at 1,525 feet, to 25° Baumé in the Sinclair Oil and Gas Company's No. 1 Ptak at 4,625 feet.

ANALYSIS OF OIL

Table V gives an analysis of oil obtained from the Sinclair Oil and Gas Company's No. 15 Bryan, which is representative of the oil produced at Damon Mound.

A test of mixed oil from several wells on the southwestern side of the field gives the analysis shown in Table VI.

PRODUCTION

Production curves.—The field-production curve, if we may call it a curve, is little more than an irregular group of sharp peaks and depressions, influenced by the performance of individual wells. However, it tells us in graphic form the story of Damon Mound production by months, for a period of seven years ending December 31, 1924. The crest of the curve was reached during the month of

TABLE V

Gravity	23.8° Baumé	Pour	0
Flash (Cleve)	180	Basic sediment and water	0.1 per cent
Fire	235	Sulphur	0.103
Viscosity at 100° C.	94	Color	Green

DISTILLATION

Per Cent	Temperature F.	Gravity Baumé	Per Cent	Temperature F.	Gravity Baumé
Start	302	....	45	590	23.9
5	440	36.8°	50	613	23.1
10	468	31.6	60	649	22.5
15	487	29.7	65	657	23.2
20	504	29.6	70	660	24.5
25	517	27.7	75	665	25.2
30	536	26.5	80	676	25.3
35	553	25.8	85	680	25.1
40	571	24.9			

Pour at end, 65° F.

TABLE VI

Gravity	21.8° Baumé
Flash	200
Viscosity at 100° C.	130
Pour	0
Basic sediment and water	.5 per cent
Italian tar test	.6 per cent
Color	Green

Refining Yields

	Per Cent
Naptha	2
Gas oil	45
Lubricating oil	36
Fuel oil	14
Loss	3

December, 1920. From that time to the present, decline has been the rule. At the end of 1922, this decline amounted to 53 per cent; at the end of 1923, 64 per cent; and judging from the present rate of production, the decline of 1924 should closely approximate 73 per cent.

The decline of initial production per well is correspondingly sharp, and the decrease of pressure within the producing horizon has reached a point where it is now necessary to pump all wells. No two wells produce alike, but the majority show high initial production with rapid decline, the curve flattening out into an irregular line of low gradient extending for a period of several years. The performance of an individual well is largely governed by the character of the producing horizon, mechanical condition of the well, and the method of operation. Fine sand or sticky shale sometimes clogs the screen or causes a "sanded" condition which interferes with the natural flow of oil. Improper screen-settings, leaking casing-seats, split casing, and other mechanical defects also alter the performance of the well. The practice of controlling the rate of initial flow in large wells by means of chokers results in a decline curve which does not represent the true performance of the well under open-flow conditions.

Figures 3, 4, and 5 show the monthly production of the Humble Oil and Refining Company's Nos. 1 and 2 Bryan and No.2 Gallagher

Drilling and production methods.—All wells are drilled by the rotary method, using a fish-tail or roller bit as the occasion demands. Casing is generally set in gumbo or rock immediately above the producing horizon, with from one to seven joints of screen according to the thickness and distribution of the producing sand. The gauge of screen is usually 80-mesh. The cost of drilling and completing a 3,000-foot well, including all items of expense, approximates $25,000.

The initial production of flowing wells is generally free from water and emulsion, but the oil from all wells eventually requires dehydration. The Tret-o-lite system is used for this purpose. The dehydrated oil is transferred into storage tanks and later pumped through a pipe line to West Columbia, and into the main line of the Sinclair Pipe Line Company, which extends to the Sinclair Refinery at Sinco.

SULPHUR

Sulphur deposits were discovered at Damon Mound in 1916, and since that time fifty-two wells have been drilled and a steaming test made in the field to determine the value of these deposits. All wells were drilled with a rotary rig, using the core barrel at frequent intervals. In fact, all important sulphur-bearing horizons were cored throughout.

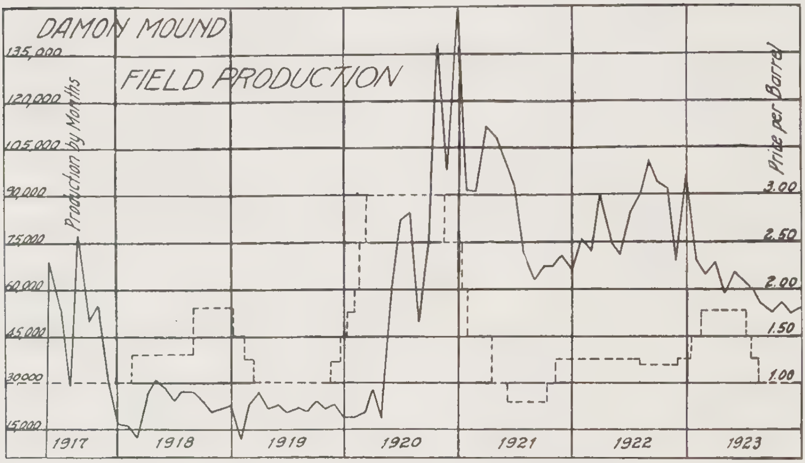

FIG. 3

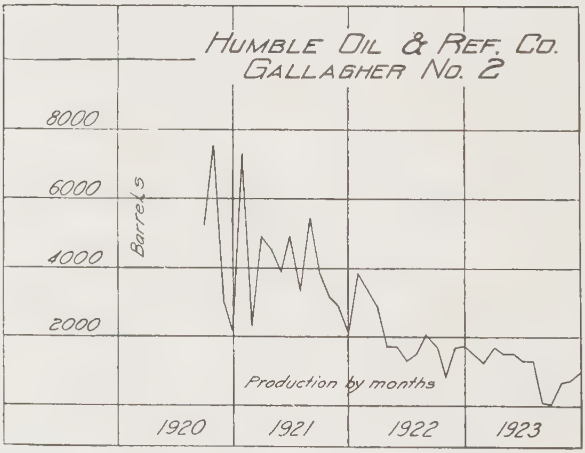

FIG. 4

The areal distribution of the sulphur has been determined, and although traces occur at many points on the dome, the only deposit of importance is confined to an area of 120 acres on the northern portion of the mound.

The sulphur occurs below the limestone and extends downward at intervals to within a few feet of the salt core. The principal sulphur-bearing horizon lies about midway between the limestone and top of the salt. Sulphur is disseminated in crystal form throughout the porous spaces of gypsum and anhydrite deposits, as a secondary or replacement deposit. The crystals vary in size from small forms to several inches in length, and the sulphur is very pure. Several theories have been advanced to explain the presence of sulphur deposits in dome material, and although nothing has been proven definitely, it is generally believed that they were formed from gypsum and anhydrite by a reducing medium such as petroleum or other hydrocarbon. The presence of heavy oil in and above the cap rock may indicate that such a reaction has taken place.

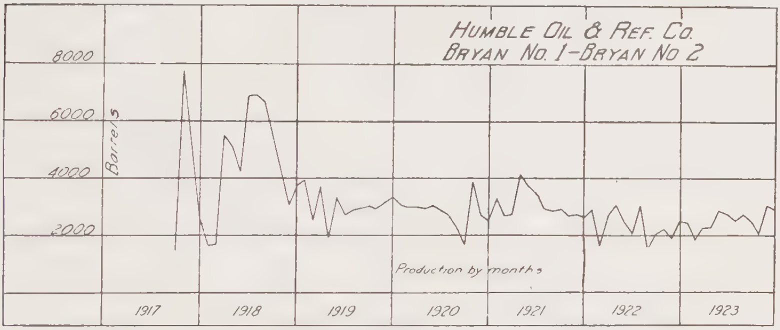

FIG. 5

The total thickness of sulphur is shown by contour lines on Figure 6. These lines express the combined sulphur content in feet as though it were present in one solid bed of pure sulphur.

CONCLUSION

In conclusion it may be added that the upper portion of the dome does not offer sufficient inducements to warrant further drilling for oil. This area is confined within the 1,000-foot contour on the salt and probably extends a little beyond its southern limits. Approximately one-third of all wells drilled at Damon Mound are located in this area. These tests are widely distributed and resulted in failures at every point. No productive horizons were found, and the underlying formations are extremely variable and apparently broken.

If new sources of supply are to be found, we must look for them in untested areas around the periphery of the dome. The periphery has been fairly well tested with the exception of an area on the north and northwestern sides, extending around the dome for a distance of 6,000 feet. It is possible that commercial production may be found within this area. However, steep dips are present at both ends, and they no doubt indicate that if oil is found, the productive area will be confined to a rather narrow strip surrounding the salt plug. Forty per cent of all wells drilled on the periphery of the Damon Mound salt dome obtained oil. Commercial production is not to be expected from available formations below the Oligocene.

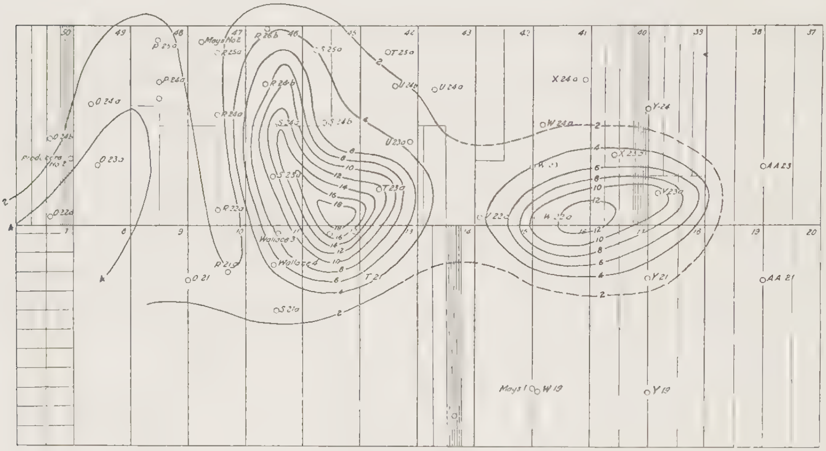

FIG. 6.—Contours showing aggregate thickness of sulphur, Damon mound

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THE STRATTON RIDGE SALT DOME, BRAZORIA COUNTY, TEXAS[1]

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ABSTRACT

The Stratton Ridge salt dome is a characteristic Gulf Coast salt dome. It has a low topographic mound. Salt and cap rock have been drilled into in many wells. The dome has been delineated roughly by deep wells on three sides. It is elongated in a northeast-southwest direction. The Oligocene and Miocene beds are sharply upthrust, do not extend over the top of the dome, and near the salt are overlain conformably by the Pliocene beds, all but the lower beds of which lie fairly flat across the top of the salt. The stratigraphic section (Recent to Vicksburg Oligocene) has been worked in considerable detail by microscopic study. Lists are given of the occurrence of the microscopic and megascopic fossils. Upthrust of the salt core took place during or just prior to the Lower Oligocene, but most of the deformation came between the Oligocene and Early Pliocene. Although many tests have been put down, only two small producers have been obtained, from around 4,300 feet. Commercial production has not been established.

INTRODUCTION

LOCATION

The Stratton Ridge salt dome is in the west half of the Jared E. Groce five-League Grant, in the southern part of Brazoria County, Texas, about 10 miles south of Angleton, and 7 miles north of Freeport. Both of these towns are served by the Houston and Brazos Valley Railroad. The dome is about midway between Hoskins Mound on the north and Bryan Heights on the south, both in Brazoria County.

HISTORY

After the discovery of oil at Spindletop in 1901, all similar structures assumed interest and value as being indicative of potential oil fields. The existence of the topographic high now called Stratton Ridge was doubtless known for some time before active prospecting began there, but it was not until February, 1913, that drilling commenced on this dome. The attention of J. Dannenbaum, of Houston, had been attracted to this area by the topography and the presence of gas in a water well near Stubblefield Lake. Between February and July, 1913, two wells were drilled by Mr. Dannenbaum on the Stratton farm near the top of the ridge. These two wells were abandoned or lost at 1,058 and 854 feet respectively. Neither produced oil nor penetrated the salt. They did, however, prove the presence of gypsum and anhydrite on this dome, which induced further exploration. Well No. 2 reported a gas show at 839 feet. These wells undoubtedly would have encountered the salt had they been drilled to 1,300 feet.

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[1] Published by permission of Mr. E. T. Dumble, consulting geologist for the Southern Pacific Company.

The next development at Stratton Ridge was in 1915–16, when Farish *et al.* drilled three wells, two on the Seaburn farm and one on the Tolar and Dannenbaum 517-acre tract. These were well down on the east side of the ridge, and though all were drilled to more than 2,000 feet, none of them encountered salt. Seaburn No. 2 is reported to have had an oil show at 1,920 to 1,950 feet, and a gas show from 2,115 to 2,150 feet. The total depth of this well was 2,758 feet, and was the deepest test of the three.

Between August, 1917, and April, 1919, the Roxana Petroleum Corporation drilled four wells on the south end of the ridge. The first three finished in gypsum or anhydrite, and the fourth penetrated the salt at 1,334 feet. This was the first well drilled into salt at Stratton Ridge.

Since the first part of 1919, the Freeport Sulphur Company has carried on an almost continuous drilling campaign on the northeast end of the ridge, with twelve wells on the Tolar and Dannenbaum tract and three on the Seaburn farm. Tolar and Dannenbaum No. 9, completed May 12, 1922, had good shows of oil and gas from 3,100 to 4,300 feet, and the well flowed at a reported rate of 1,200 to 1,500 barrels for about a week, when it sanded up, and though worked over for some time, never made a commercial well. Tolar and Dannenbaum No. 11 is one of the two producing wells at Stratton Ridge. It was completed in 1923 at a total depth of 4,386 feet, was put on the pump about November 1 of that year, and averages about 75 barrels a week.

The Humble Oil and Refining Company took an active interest in development at Stratton Ridge from June, 1919, to April, 1921, drilling six wells on the Seaburn land, on the south and east sides of the ridge. This company also drilled three dry wells on the west side of the ridge, two on the Brock and one on the Shea and Storrie tracts.

About December, 1919, and February, 1920, the Texas Company drilled two dry holes a mile or two west of Stratton Ridge on their Cochran and McClure leases. About this time, also, the Castell Oil Company, drilling on the Storrie farm on top of the ridge, reported a strong gas blow-out at 750 feet.

Between August 1 and November 16, 1922, the Empire Gas and Fuel Company drilled unsuccessfully to 4,671 feet in their Wilson No. 1 at the north end of the ridge.

The Fairchild Petroleum Company (C. C. Cannan *et al.*) completed their Boggs No. 1 at 4,575 feet as a dry hole at the north end of the ridge during the latter part of 1923. On March 7, 1924, Boggs No. 2 was completed at 4,287 feet and flowed about 1,500 to 2,000 barrels of oil and some water for a few days. It is now pumping, but the amount of production is not known. A total of thirty-eight wells have been drilled at Stratton Ridge. Wells now drilling are the Freeport Sulphur Company's No. 12, Tolar and Dannenbaum at the north end of the ridge, and the Associated Oil Company's Perry No. 1 at the south end of the ridge, near Chubb Lake.

PHYSIOGRAPHY

The Gulf Coastal Plain has been divided by some writers into two divisions. The upper or interior division ranges from 165 to 340 feet in elevation and slopes gently seaward at the rate of 1 or 2 feet per mile. Along the immediate coast and for several miles inland, the lower division shows an even gentler slope of less than 1 foot per mile seaward.

Rising from this lower, featureless plain are several prominent mounds or dome-shaped hills of varying heights and dimensions, belonging to what is known as the Coastal Mound class of salt domes. Stratton Ridge is one of these. Others in the immediate vicinity are

West Columbia, Damon Mound, Hoskins Mound, and Bryan Mound in Brazoria County, and Big Hill in Matagorda County.

The salt-dome mound known as Stratton Ridge (Fig. 1), on account of its somewhat elongated form, is a poorly defined ridge with a flat top and relatively steep sides. A slight depression is noted on top and near the center of the ridge. The long axis of the ridge

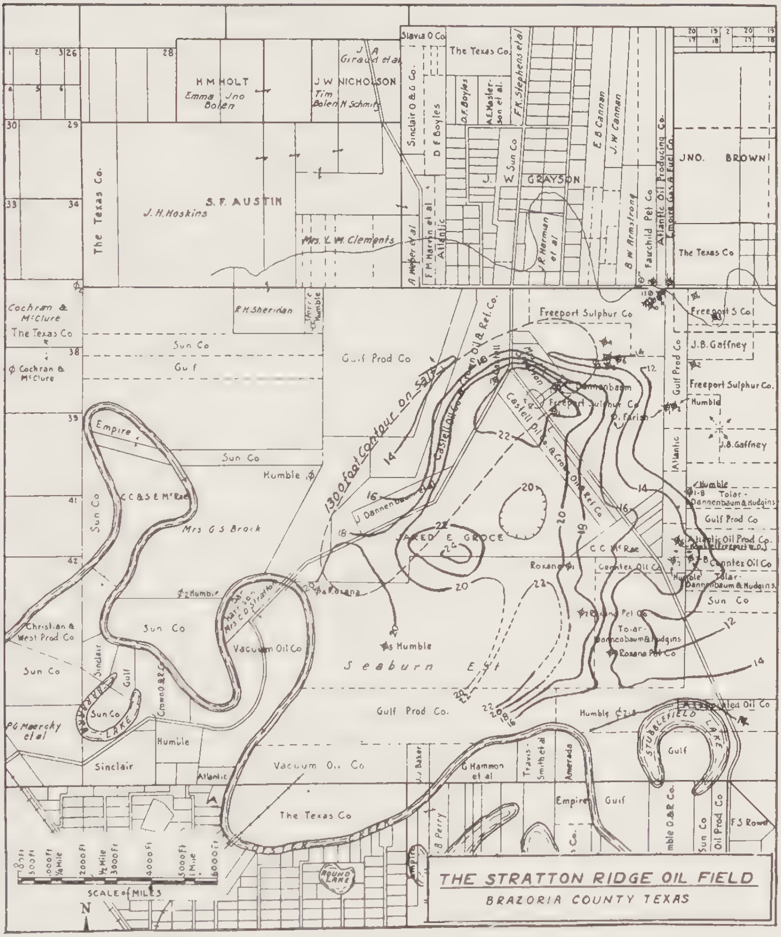

FIG. 1.—Topography of north end of Stratton Ridge Salt Dome. Contour interval, 2 feet; datum, sea-level.

trends about N. 30°E. This axis if extended would pass through Hoskins Mound 12 miles to the northeast and through Bryan Mound 12 miles to the southwest. The ridge is about 3.5 miles long from northeast to southwest, and about 2 miles wide across its shorter axis. It has a general elevation above sea-level of about 20 feet, though at one or two points its summit reaches 25 feet. The country about the ridge is low, flat, and marshy. Oyster Creek flows in a meandering course across the south end of the ridge, and Big Slough cuts across the north end.

A number of small, semicircular ponds or "ox-bows" such as Stubblefield Lake, Chubb Lake, and Barbara Lake are old meanders of Oyster Creek. These are all shallow ponds and are frequently dry in summer.

The age of the salt-dome mound as we now see it is probably Pleistocene or Recent.

SURFACE GEOLOGY

The areal geology of the region as a whole is simple and needs only be briefly stated here. The surface formations are:[1] (1) Recent material. A series of Recent sands, gravel, and river alluvium extends along the coast and up Brazos River and larger streams for varying distances and with different widths. On the coast the Recent materials appear as a strip of marshy country about 6 miles wide extending from Chocolate Bayou westward to and beyond Brazos River. This marshy strip of land envelops the three mounds of Hoskins, Stratton Ridge, and Bryan Heights. Big Hill, in Matagorda County, may also be included in this group. The immediate coast or shoreline is a mixture of sand with an occasional lens of clay. (2) Pleistocene. This series, generally known as the Beaumont clays, lies north of and in places apparently grades into the belt of marshy country occupied by the Recent material. The Beaumont clays appear as a broad belt of black, brown, and dark blue clays with sand lenses and nests of calcareous nodules. This series forms heavy, dark-colored or black soil. The clays envelop the West Columbia and Damon Mound domes.

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[1] Data largely from private report by William Kennedy.

These are the surface formations with which the Stratton Ridge salt dome comes in contact. The underlying beds, or their inland equivalents, outcrop far to the north and west and will be treated in a later section of this paper.

SUBSURFACE GEOLOGY

General knowledge of underground conditions at Stratton Ridge has been gained from study of all available drillers' logs and from paleontological data derived from study of cuttings and cores secured from certain wells drilled by the Freeport Sulphur Company, the Roxana Petroleum Corporation, and the Humble Company.

From its general structure and the presence of gypsum, anhydrite, and salt, Stratton Ridge may be classed as a true salt dome, but one of peculiar shape and extraordinary areal extent.

THE SALT CORE

In form, the salt core at Stratton Ridge appears to be long, narrow, flat-topped, and rather steep-sided. The north and east sides of the salt core have been shown by drilling to be steep, but what the slope on the south and west may be is not definitely known. Nine wells have been drilled to the salt on this dome, six scattered over the top of the ridge and three on the northeast end The six wells drilled on top of the ridge encountered the salt at a depth of slightly over 1,300 feet, and the 1,300-foot contour drawn on the salt, as found in these six wells, outlines the top of the salt core fairly well (Figs. 1 and 2), except at the extreme south end, where no wells have been drilled through the gypsum. The top of the salt core as now known has the shape of a long, narrow ellipse, with the long axis extending about 2 miles N. 55°E., roughly paralleling the coast-line at this point. The short axis of the salt core extends about $\frac{3}{4}$ mile northwest and southeast.

The relation of the top of the known salt core to the topographic ridge is shown in Figure 1, where the salt appears to lie somewhat down the northwest flank of the surface ridge. The relation of the salt core to the overlying gypsum and anhydrite cap is shown in Figure 2.

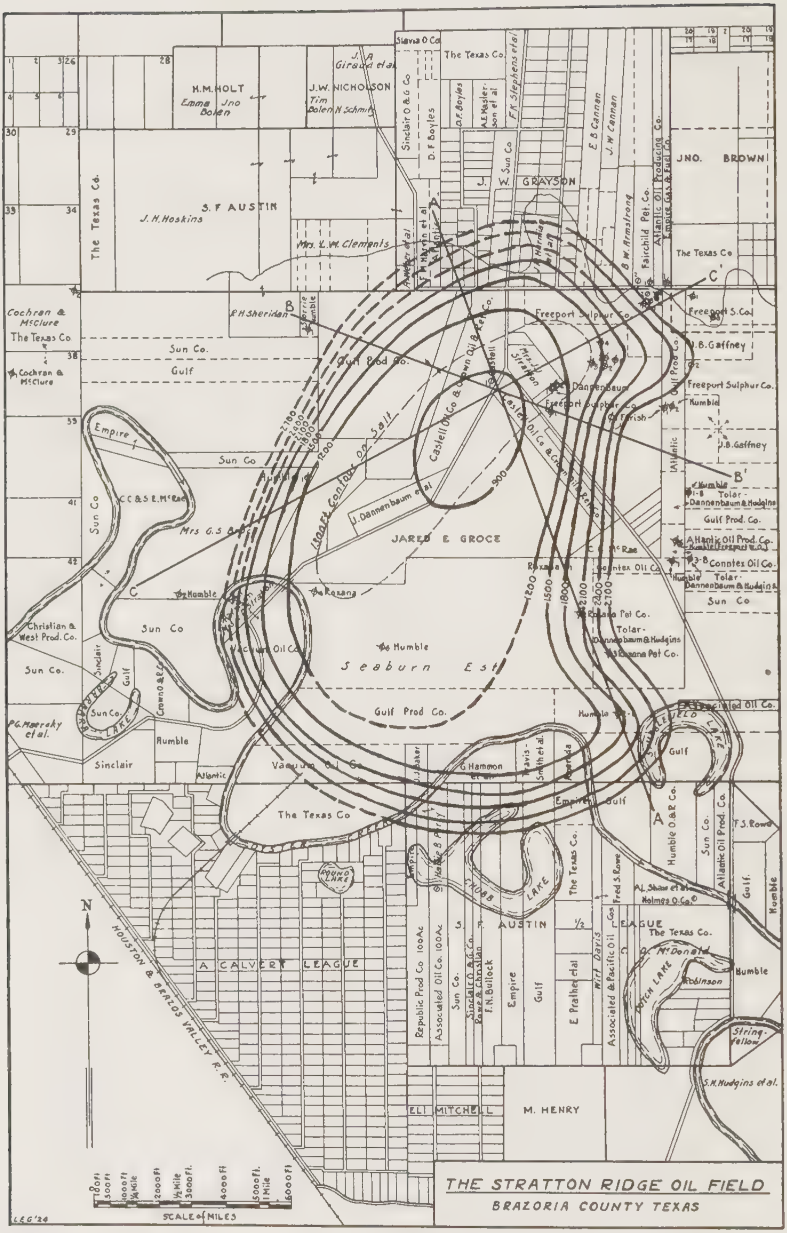

FIG. 2.—Contours on gypsum and anhydrite cap, Stratton Ridge salt dome. Contours based on elevation below sea-level. Contour interval, 300 feet.

The following wells have encountered salt, the first six near the top of the dome, the last three on the northeast end of the dome.

Company	Well	Depth to Salt
		Feet
Freeport Sulphur Company........	No. 1 Tolar and Dannenbaum	1,308
Freeport Sulphur Company........	No. 2 Tolar and Dannenbaum	1,316
Freeport Sulphur Company........	No. 4 Tolar and Dannenbaum	1,319
Roxana Petroleum Corporation.....	No. 4 Seaburn	1,334
Humble Oil and Refining Company..	No. 1 Brock	1,471
Castell..........................	No. 1 Storrie	1,250–1,300±
Freeport Sulphur Company........	No. 10 Tolar and Dannenbaum	2,633
Freeport Sulphur Company........	No. 1 Seaburn	4,765
Freeport Sulphur Company........	No. 2 Seaburn	2,473

The steep dip on the salt at the northeast end of the ridge is well shown by the records of the Freeport Sulphur Company's Tolar and Dannenbaum Nos. 8 and 10 (Fig. 5), the former being 150 feet north of the latter. Well No. 10 entered salt at 2,633 feet and continued to 3,255 feet, where the well was abandoned; No. 8 was drilled to 3,142 feet and showed no salt at that depth. This indicates an essentially vertical side to the salt core between these two wells. Section C–C′ (Figs. 2 and 3) passes through the Freeport's Tolar and Dannenbaum Nos. 4 and 10 and Seaburn No. 1 at the northeast end of the ridge. The difference in elevation on the salt between Tolar and Dannenbaum No. 4 and Seaburn No. 1, about 3,500 feet apart, amounts to 3,446 feet, indicating an average dip of about 45 degrees toward the northeast. The dip between Tolar and Dannenbaum No. 10 and Seaburn No. 1, however, is somewhat steeper than the dip between Tolar and Dannenbaum Nos. 4 and 10. Section B–B′ (Figs. 2 and 3) passes through the Freeport's Tolar and Dannenbaum No. 1 and Farish's Tolar and Dannenbaum No. 1 on the east side of the ridge. Freeport No. 1 showed salt at 1,308, while the Farish well, 1,800 feet to the east, showed no dome material when abandoned at 2,082 feet.

An irregularity in the salt core is noted at the northeast end of the dome near the Freeport's Seaburn No. 2. This well found the salt at 2,473 and drilled into it 100 feet. The Seaburn well is 2,750 feet east of the Tolar and Dannenbaum No. 2, which encountered the salt at 1,316 feet, and is 2,150 feet south of the Seaburn No. 1, which encountered the salt at 4,765 feet. Farish's No. 2 Seaburn, only 1,500 feet south of the Freeport's Seaburn No. 2, drilled to 2,758 feet, but did not encounter any salt, finishing in "sandy gyp." It is believed that the Freeport's Seaburn No. 2 is located on a narrow steep-sided ridge of solid salt projecting from the main core and plunging eastward. This plunging ridge or "nose" is reflected in the overlying gypsum cap and also to some extent in the surface topography.

On the west and south sides of the ridge little work giving a clue to the structure of the salt has been done. The Humble's Brock No. 1 and the Roxana's Seaburn No. 4 encountered salt and are probably close to the edge of the flat top of the salt core. The Humble's Shea-Storrie No. 1 on the northwest side of the dome reached 4,086 feet without finding salt or gypsum, and their Brock No. 2 was drilled to 2,904 and found no dome material at that depth. These wells seem to indicate a steep west side to the salt core, but definite information is lacking until further drilling is done here. The position of the salt on the south side is equally problematical.

CAP

Above the main salt core at Stratton Ridge is a gypsum and anhydrite cap of irregular thickness, like an inverted saucer in form,[1] thickest toward the center and gradually thinning toward the edges. The wells along Section C–C¹ (Figs. 2 and 3) illustrate this condition. The Freeport Sulphur Company's Tolar and Dannenbaum No. 1 and the Castell Oil Company's Storrie No. 1, drilled near the top of the ridge, both show about 400 feet of gypsum. The Humble's No. 1 Brock, about 1¼ miles southwest of the Castell well, shows 169 feet of gypsum, and the Freeport's Tolar and Dannenbaum No. 4, 3,500 feet northeast of the Castell well, shows about 90 feet. Freeport's Tolar and Dannenbaum No. 10, on the northeast flank of the salt, records only 16 feet of gypsum, and their Seaburn No. 1, farthest northeast, enters the salt at 4,765 without recording any gypsum at all.

Sixteen wells at Stratton Ridge have drilled into gypsum and anhydrite. In some of the wells, especially those on the top of the ridge near the north end, the gypsum appears to be broken into two

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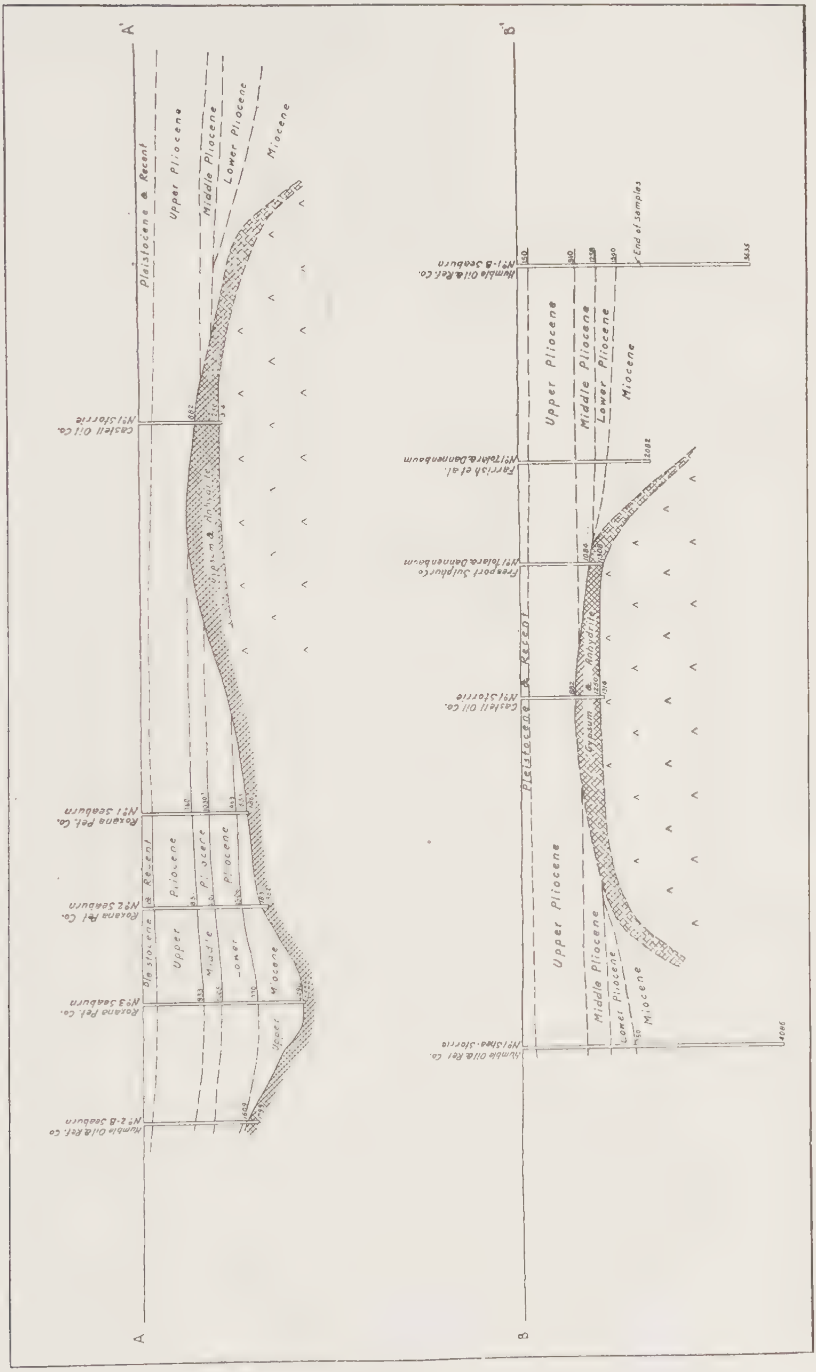
[1] Private report by William Kennedy.


A′
A
B′
B
Pleistocene & Recent
Upper Pliocene
Middle Pliocene
Lower Pliocene
Miocene
Gypsum & Anhydrite
Castell Oil Co. Nº1 Storrie
Roxana Pet. Co. Nº1 Seaburn
Roxana Pet. Co. Nº2 Seaburn
Roxana Pet. Co. Nº3 Seaburn
Humble Oil & Ref. Co. Nº2-B Seaburn
Humble Oil & Ref. Co. Nº1-B Seaburn
End of Samples
Farrish et al. Nº1 Tolare-Dannenbaum
Freeport Sulphur Co. Nº1 Tolare-Dannenbaum
Humble Oil & Ref. Co. Nº1 Shea-Storrie
3635
2082
4086
882
1084
1108
1250
1314

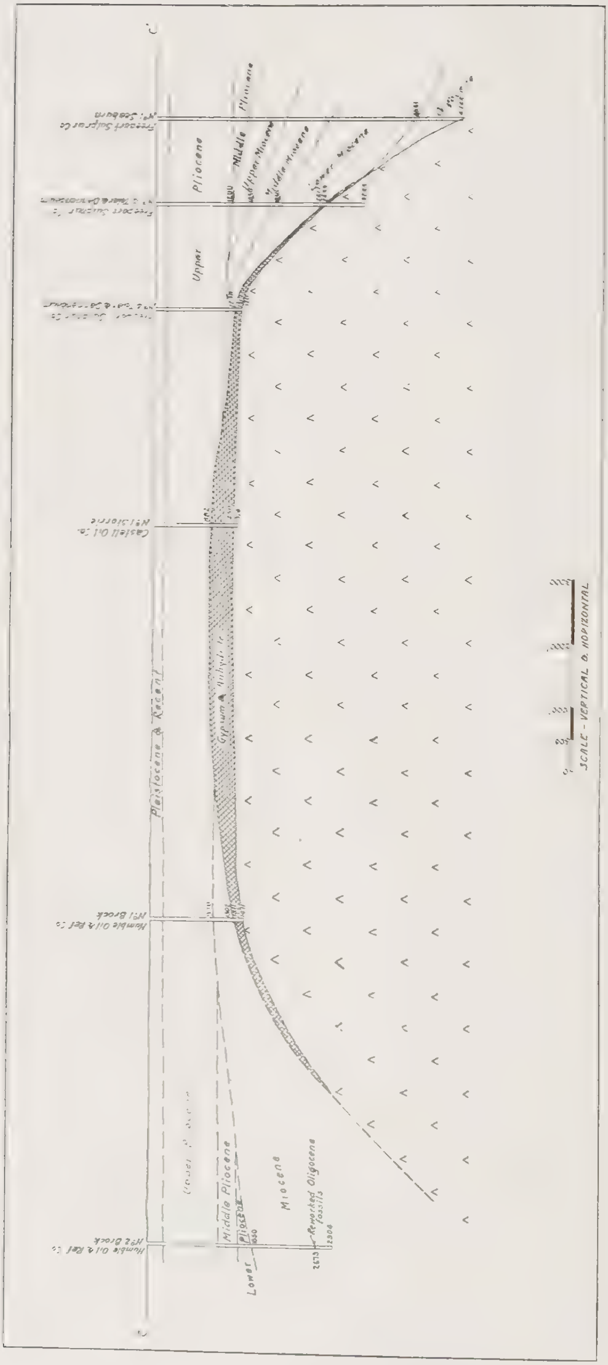


FIG. 3.—Structural sections through the dome

or more beds separated by sand or lime. In other wells, especially at the south end of the ridge, the gypsum seems to be a solid bed or interstratified with thin layers of anhydrite. These conditions may be illustrated by the driller's logs of some of the wells.

The log of the Freeport Sulphur Company's Tolar and Dannenbaum No. 1, near the crest of the ridge, shows the following conditions:

	Thickness	Depth
	Feet	Feet
Gypsum	101	1,011
Sand and shale	5	1,016
Gypsum	10	1,026
Sand rock	20	1,046
Gypsum	6	1,052
Boulders	10	1,062
Rock	22	1,084
Gypsum	185	1,269
Sand	6	1,275
Gypsum	33	1,308
Salt	....	....

In No. 2 of the same company's wells on this lease, 7 feet of lime occur in the middle of the gypsum bed. The log shows:

	Thickness	Depth
	Feet	Feet
Gypsum	40	1,252
Lime	7	1,259
Gypsum	57	1,316
Salt	....	....

Well No. 4, however, only 500 feet from No. 2, shows solid gypsum from 1,238 to 1,319 feet, underlying a series of gumbos with some lime rock. Salt was encountered at 1,319 feet.

Tolar and Dannenbaum No. 6 again shows the divided condition of the gypsum. The log is as follows:

	Thickness	Depth
	Feet	Feet
Gumbo, shale, and lime	138	1,292
Lime	28	1,320
Calcite	6	1,326
Blue lime	12	1,338
Gypsum	....	....

At the southern end of the ridge, the four wells drilled by the Roxana all encountered the gypsum, but only No. 4 drilled through it. Well No. 1 shows solid gypsum from 1,655 to 1,686 feet. In the No. 2, 3, and 4 wells the log shows the following conditions:

Roxana No. 2	Thickness	Depth
	Feet	Feet
Lime	9	1,851
Anhydrite and some lime	3	1,854
Gypsum	101	1,955
Roxana No. 3		
Clay	37	2,490
Anhydrite	32	2,522
Roxana No. 4		
Lime and gypsum	9	1,003
Anhydrite	17	1,020
Gypsum	293	1,313
Gypsum and salt	21	1,334
Rock salt	....	....

In the Humble's Seaburn No. 5, at the south end of the ridge, the gypsum appears in the form of blue and white bands from 1,053 to 1,121. Lime and gypsum mixed also occur from 1,008 to 1,023. The log shows:

	Thickness	Depth
	Feet	Feet
Lime and gypsum	15	1,023
Sand rock	12	1,035
Rock	10	1,045
Gypsum and shell	8	1,053
Solid gypsum	68	1,121

An irregularity in the depth to the gypsum is found at the southeast end of the ridge (Sec. A–A′, Fig. 2). The Humble Company's Seaburn B-2 encountered gypsum at 1,609 feet and continued in it for nearly 200 feet. This well is 2,000 feet south of the Roxana's No. 3, which found gypsum first at 2,490 feet.

So far as it has been drilled into, the gypsum has been shown to be close-grained, hard, and compact, especially the thicker beds. The broken, cavernous conditions found in some of the domes, and the large flows of black sulphur water and hydrogen sulphide gas are absent. It may also be noted here that since sulphur is of secondary origin and due to the destruction of the gypsum, the prospects for finding sulphur on this dome are poor.[1] No definite limestone cap appears above the gypsum horizon on this dome, but for several hundred feet above the gypsum a series of interbedded limestones, sands, and gumbos is shown in many of the well logs.

STRUCTURE OF SURROUNDING SEDIMENTS

Information regarding the various formations penetrated by the drill on the Stratton Ridge salt dome has been acquired through microscopic study of well cuttings and cores, this work being done by the paleontological department of the Rio Bravo Oil Company. The data at hand are not sufficiently complete to permit making detailed sections of the formations, but the larger divisions may be recognized even though hard-and-fast lines cannot be drawn between them. This lack of definiteness is due mainly to three factors: (1) The well samples were in many cases cuttings rather than cores, especially in those earlier wells drilled before coring became common; (2) complete sets of samples were seldom available from any given well; (3) further, the paleontological data show that conditions of deposition here were unique and different from those found at any other coastal dome from which material has been studied. The evidence points to a state of shallow marine submergence, with frequent incursions and withdrawals of the sea in the vicinity of this dome during Miocene and Pliocene time. This condition persisted through the Pleistocene and even into the Recent, and gave rise to a uniformity of lithology and similarity of faunas which render the separation of minor geological horizons difficult. However, the Pleistocene, Pliocene, Miocene, and Oligocene have been recognized definitely, and the approximate contacts between them have been determined The West Columbia dome is the only other known to us where this nearly continuous marine condition of the Miocene and Pliocene is even closely approximated. Other domes show evidence, usually, of only one or two marine incursions during the Miocene. Five and possibly more are found at Stratton Ridge.

Cuttings and cores from the following wells have been the source of data on the nature of the underlying sediments: Roxana Petroleum Corporation's Seaburn Nos. 1, 2, 3, and 4, which give sections of the Pleistocene, Pliocene, and top of the Miocene; Freeport Sulphur Company's Tolar and Dannenbaum Nos. 9, 10, 11, and 12, and Seaburn Nos. 1, 2, and 3, all below 2,000 feet, give Miocene and Oligocene sections; Humble Company's Brock Nos. 1 and 2, Shea-Storrie No. 1, Seaburn B-1 and No. 6 give sections of the Pliocene and Miocene; a few samples from the Castell Oil Company's Storrie No. 1 give a section of part of the Pliocene.

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[1] Private report by William Kennedy.

The information regarding the formations encountered in the above wells permits deductions as to the attitude of the beds surrounding the salt core. The facts resulting from this study are set forth below, and the interpretation of these facts is shown on the accompanying cross-sections in Figures 3 and 5.

The contact between the Pliocene and Miocene beds is recognized in the Roxana's Seaburn 1, 2, and 3 at the following depths: No. 1 at 1,469 feet, No. 2 at 1,506 feet, No. 3 at 1,750 feet. No. 4 did not encounter any Miocene, and the lower part of the Pliocene is missing. In the Humble's No. 1 Shea-Storrie, the Pliocene-Miocene contact is placed at about 1,800 feet, and in their Seaburn B-1, at about 1,540 feet. The Humble's No. 2 Brock entered beds of Miocene age between 1,300 and 1,600 feet, but the contact cannot be placed closer, as no samples were taken in this interval. In Brock No. 1, the Miocene beds are first encountered at about 970 feet.

In the Humble's Seaburn No. 6, Miocene was first encountered at about 1,500 feet. The Castell Oil Company's Storrie well at the crest of the ridge found no Miocene sediments; in fact, the lowest part of the Pliocene seems to be missing.

In studying the samples from the Roxana wells, it is found that three divisions may be made within the Pliocene, largely on the basis of lithology. These three divisions are shown on Section A–A^1 in Figure 3, and are more fully described in the paragraph on "Stratigraphy." In the Castell Oil Company's No. 1 Storrie, on the crest of the ridge, from which only a few samples were available for study, it appears that probably only the upper zone is present. In the Roxana No. 4, on the west side of the ridge (not shown on section), the lowest zone of the Pliocene was not found. The well entered the gypsum cap at 1,003 feet. The lithological divisions of the Pliocene recognized in the Roxana well samples were also observed in the Humble's Seaburn B-1, and show about the same thickness as in the Roxana wells except that the lowest member is somewhat thinned. In the Humble's Brock No. 1, only the upper Pliocene is thought to be present and seems to overlie the upper Miocene at 970 feet.

The upper Miocene and the lower Pliocene sediments apparently do not pass over the top of the dome, but lap up around the sides. The upper portion of the Pliocene passes over the top of the salt core. The Pliocene beds, in the vicinity of the Roxana wells at least, show comparatively little uplift, possibly about 200 feet.

Nothing is known of the Miocene-Oligocene contact and the attitude of the lower formations save at the northeast end of the ridge. Samples studied from six of the wells in this group show definitely that they were drilled into the Oligocene. These wells are the Freeport Sulphur Company's Tolar and Dannenbaum 9 and 11, Seaburn 1 and 3, and Cannan's Boggs No. 1 and No. 2. It is also probable that the Empire's Wilson No. 1, 4,671 feet in depth, penetrated the Oligocene, but definite information is lacking. The location of these closely grouped wells is shown on the large-scale map in Figure 4.

Within the Miocene, the three divisions designated upper, middle, and lower are recognized on the basis of foraminiferal and lithological changes. Three divisions are also recognized in the Oligocene.

No samples were available for study from Tolar and Dannenbaum No. 8. In No. 10, the first samples received were from 1,235 feet and were in the upper zone of the Miocene. Middle Miocene beds were recognized from about 1,400 to 1,850 feet, and the lower Miocene was found from 1,850 feet, the top of the cap at 2,617 feet.

Consecutive samples were received from Tolar and Dannenbaum No. 9 beginning at 3,000 feet and were found to be lower Miocene to 4,005 feet.

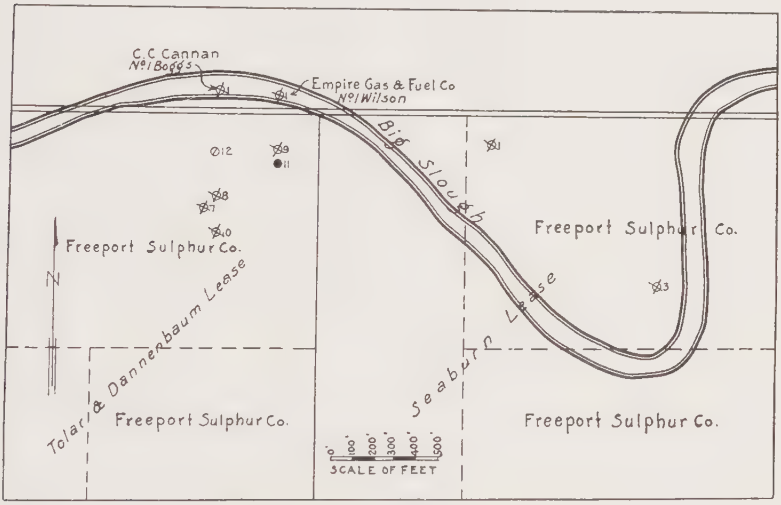

FIG. 4.—Map showing location of wells at northeast end of Stratton Ridge

Oligocene continued to the bottom of the hole at 4,364 feet. The lowest Oligocene or *Marginulina* zone was identified at about 4,350 feet. The sand from which this well produced for a short time (4,344-4,364 feet) evidently belongs in the lowest Oligocene.

In a few samples from Tolar and Dannenbaum No. 11 taken at about 3,500 feet, lower Miocene Foraminifera were found. Samples from about 4,050 feet were well down in the Oligocene, and the lowest or *Marginulina* zone was recognized at 4,140 feet. Oligocene continued to 4,350 feet, where the well entered a non-fossiliferous zone of indeterminate age. The production from this well is obtained at 4,249–4,386 feet in the lowest Oligocene.

Our samples from the Freeport Sulphur Company's Seaburn No. 1 began at about 3,100 feet. Lower Miocene was encountered to 4,051 feet, and Oligocene to about 4,650 feet, the *Marginulina* zone being recognized at about 4,500 feet. Below 4,650 feet there is a non-fossiliferous zone similar to that found in Tolar and Dannenbaum No. 11. Salt was encountered at 4,765 feet.

Seaburn No. 3 drilled in middle Miocene from about 2,300 to 3,200 feet and in lower Miocene to about 3,950 feet. From this point the Oligocene was found to 4,416 feet, where the samples ended (total depth 4,442 feet). The *Marginulina* zone of the Oligocene was recognized in this well at 4,350 feet. The top of the Oligocene at 3,950 is the highest point at which this formation has been identified on this dome. It may be higher than this in other wells from which samples were not received.[1]

Samples from Boggs No. 1 taken at 4,200 feet are of Oligocene age. The *Marginulina* zone was recognized at 4,475 feet. Figure 5 is a cross-section on a horizontal and vertical scale of 500 feet to the inch drawn through the Freeport's Tolar and Dannenbaum Nos. 10, 8, 11, and 9, and shows the probable relations of the formations to the salt core at the northeast end of the ridge. The *Marginulina* zone in the lowest Oligocene is found to be 210 feet higher in No. 11 than in No. 9, and a horizon picked up at 2,422 feet in No. 10 may possibly be correlated with the formation found in No. 9 at 3,196 feet. This would indicate steeply tilted formations close to the salt core and a considerable dragging up of the lower beds alongside the salt. It seems even possible that the oil and gas encountered at 3,082–3,142 feet in Tolar and Dannenbaum No. 8 may be from upthrust Oligocene beds.

In Seaburn No. 3, the Oligocene is found to be from 100 to 150 feet higher than in Seaburn No. 1, due possibly to the effect of the salt ridge plunging away from the main core in this area.

No Oligocene was encountered in any of the deep wells drilled by the Humble on the east side of the ridge, nor in the Shea-Storrie (total depth 4,086 feet) on the northwest side of the ridge. Samples from this well at 4,015 feet, as determined by Miss Ellisor of the Humble Company, are shown to be Miocene in age.

An interesting find is reported by Miss Ellisor from the Humble's Brock No. 2, on the west side of the ridge (Fig. 3, Section C–C[1]). At 2,040 feet, reworked Oligocene Foraminifera were found in marine Miocene sediments, and again at 2,673 feet, reworked fragments of limestone carrying well-preserved Oligocene Foraminifera appeared. Beds of Miocene age occurred below. The presence of these well-preserved Oligocene fossils and fragments of limestone doubtless indicates that the Oligocene outcropped close at hand during Miocene time and that the fragments were washed out into the Miocene sea. We may also infer from the occurrence of these fossils that uplift at Stratton Ridge was going on in the Miocene, that the uplift of the Oligocene was as great or possibly greater than is indicated on the northeast side of the dome, and that the salt

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[1] The "*Discorbis* zone" of the Vicksburg has recently been recognized in Tolar and Dannenbaum No. 12 at 3,713 feet.

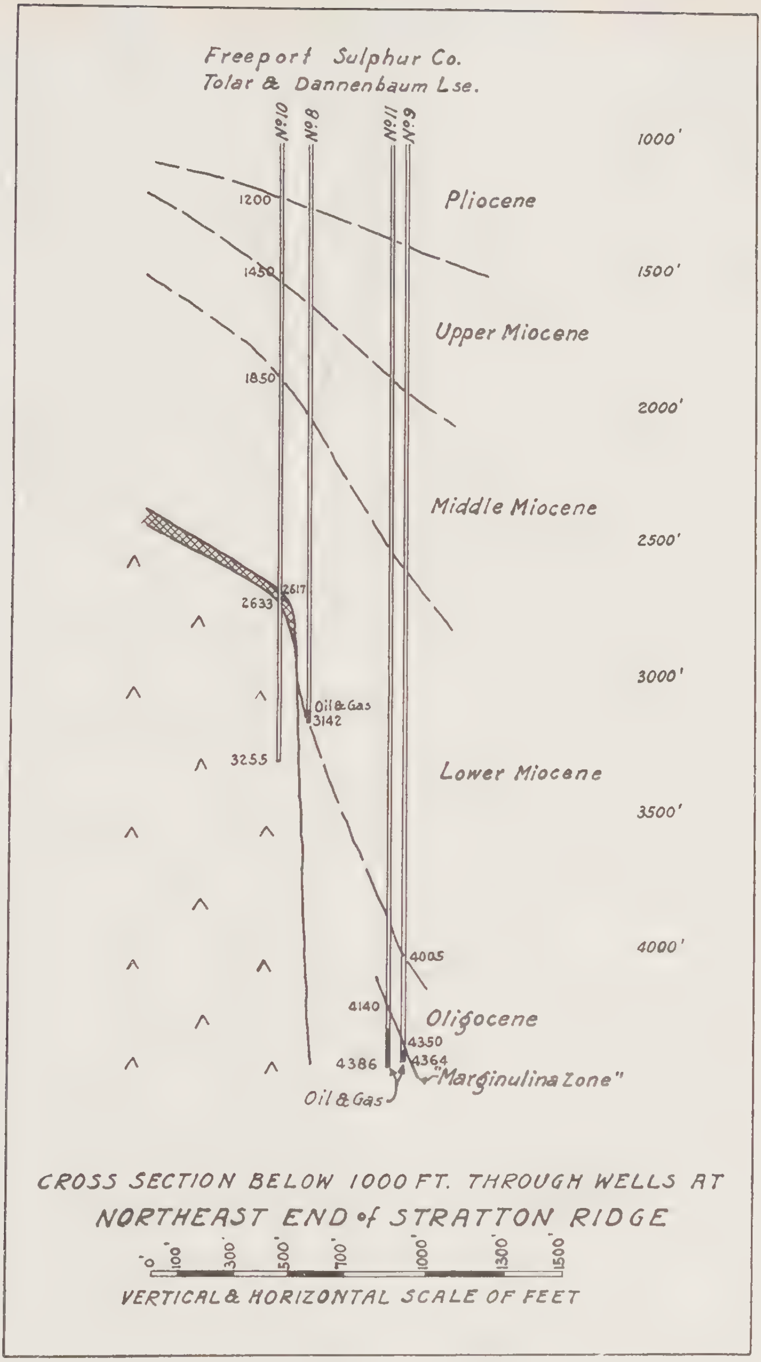
Freeport Sulphur Co.
Tolar & Dannenbaum Lse.
No. 10
No. 8
No. 11
No. 9
1000'
1500'
2000'
2500'
3000'
3500'
4000'
Pliocene
Upper Miocene
Middle Miocene
Lower Miocene
Oligocene
1200
1450
1850
2617
2633
Oil & Gas
3142
3255
4005
4140
4350
4364
4386
"Marginulina Zone"
Oil & Gas
CROSS SECTION BELOW 1000 FT. THROUGH WELLS AT
NORTHEAST END of STRATTON RIDGE
0
100'
300'
500'
700'
1000'
1300'
1500'
VERTICAL & HORIZONTAL SCALE OF FEET

FIG. 5

core may show a much steeper west side than that indicated in Section C–C[1] of Figure 3.

STRATIGRAPHY

Study of the samples from the several wells mentioned above affords basis for a generalized description of the formations from the Pleistocene to the Oligocene, and for designation of characteristic features of these sediments at Stratton Ridge.

Beds older than upper Miocene have not been penetrated, unfortunately, by wells from which continuous samples beginning at the surface are available, and samples from beds above the lower part of the Miocene have not been secured from wells which went into the lower Miocene or older formations. Furthermore, the wells which give the best record of the Pliocene and upper Miocene, the Roxana wells, are situated on the southeast side of the dome, while those from which most information regarding the older beds is gained, the Freeport wells, are located on the northeast side of the dome. The upper section from the Roxana wells must therefore be combined with the lower part of the section from the Freeport wells in order to get a complete record of the formations encountered in drilling around this dome. The most complete section of the lower formations is given in the Freeport's Seaburn No. 3, which is here taken as typical. In this well samples were obtained from depths between 1,484 and 1,525 feet which are identical in lithology and fauna with the upper Miocene section found in the Roxana's Seaburn wells.

GENERALIZED SECTION AT STRATTON RIDGE[1]

Recent and Pleistocene

Gray and yellow sand and sandy clay which contain fragments of oyster shells and a few Foraminifera, identical with forms found on Galveston Beach at the present time. These include *Rotalia beccarii* Linn., *R. beccarii* var. *galvestonensis* n. var.,*[2] *Nonionina* cf. *depressula* Walker and Jacob, *Polystomella galvestonensis* n. sp.*. The base of the Pleistocene is marked by a bed of nonfossiliferous sand, generally logged as a water sand, about 30 feet thick and consisting of well-worn, uneven-grained, moderately coarse, tan-colored sand. The thickness of the Pleistocene and Recent deposits is 100 to 200 feet.

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[1] See also graphic section, Fig. 6.

[2] Manuscript new species in this paper are designated by *.

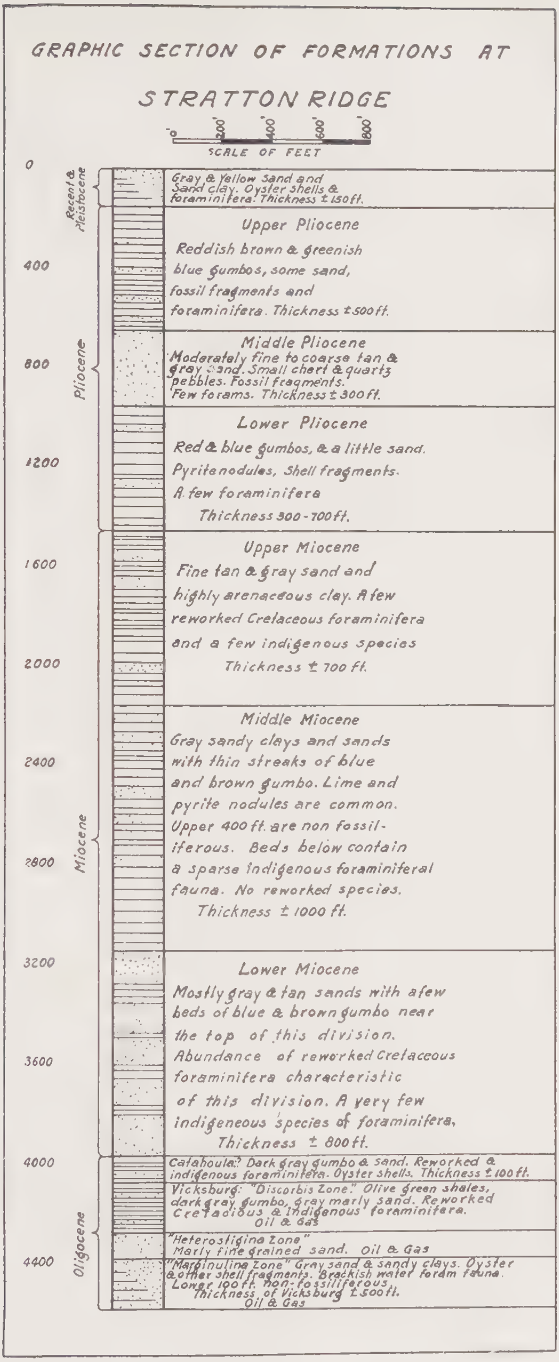
GRAPHIC SECTION OF FORMATIONS AT
STRATTON RIDGE
0
200'
400'
600'
800'
SCALE OF FEET
0
400
800
1200
1600
2000
2400
2800
3200
3600
4000
4400
Recent & Pleistocene
Pliocene
Miocene
Oligocene
Gray & Yellow Sand and Sand clay. Oyster shells & foraminifera. Thickness ± 150 ft.
Upper Pliocene
Reddish brown & greenish blue gumbos, some sand, fossil fragments and foraminifera. Thickness ± 500 ft.
Middle Pliocene
Moderately fine to coarse tan & gray sand. Small chert & quartz pebbles. Fossil fragments. Few forams. Thickness ± 300 ft.
Lower Pliocene
Red & blue gumbos, & a little sand. Pyrite nodules, Shell fragments. A few foraminifera
Thickness 300-700 ft.
Upper Miocene
Fine tan & gray sand and highly arenaceous clay. A few reworked Cretaceous foraminifera and a few indigenous species
Thickness ± 700 ft.
Middle Miocene
Gray sandy clays and sands with thin streaks of blue and brown gumbo. Lime and pyrite nodules are common. Upper 400 ft. are non fossiliferous. Beds below contain a sparse indigenous foraminiferal fauna. No reworked species.
Thickness ± 1000 ft.
Lower Miocene
Mostly gray & tan sands with a few beds of blue & brown gumbo near the top of this division. Abundance of reworked Cretaceous foraminifera characteristic of this division. A very few indigeneous species of foraminifera.
Thickness ± 800 ft.
Catahoula? Dark gray gumbo & sand. Reworked & indigenous foraminifera. Oyster shells. Thickness ± 100 ft.
Vicksburg: "Discorbis Zone." Olive green shales, dark gray gumbo, gray marly sand. Reworked Cretacious & Indigenous foraminifera.
Oil & Gas
"Heterostigina Zone"
Marly fine grained sand. Oil & Gas
"Marginulina Zone" Gray sand & sandy clays. Oyster & other shell fragments. Brackish water foram fauna. Lower 100 ft. non-fossiliferous.
Thickness of Vicksburg ± 500 ft.
Oil & Gas

FIG. 6

Pliocene

On the basis of certain constant lithological characters, we have divided the Pliocene into three divisions, designated upper, middle, and lower, respectively.

Upper division.—Reddish-brown and greenish-blue gumbos are the characteristic materials composing this part of the Pliocene. Nearly all of the cuttings when washed contain a small amount of sand, some fossil fragments, and Foraminifera. *Chara* fruit cases are also occasionally found. The foraminiferal fauna is similar to that of the Pleistocene, but the species are more varied and a few of the varieties are apparently confined to the Pliocene. The majority of the species continue into the younger period, as would be expected. The Foraminifera and other fossils found in this division are forms which indicate a shallow marine condition of deposition. The most common Foraminifera present are: *Rotalia beccarii* Linn., *Polystomella galvestonensis* n. sp.,* *Rotalia beccarii* Linn. var. *galvestonensis*,* *Polystomella striato-punctata* (Fichtel and Moll) Parker and Jones, *Textularia* n. sp., *Polystomella craticulata* (Fichtel and Moll var.). Ostracod carapaces, *Rangia cuneata*, and a number of other pelecypods and gastropods are also present in a few of the samples. The thickness of this division is about 500 feet.

Middle division.—Moderately fine to coarse, tan and gray sands form the major portion of the materials of this Pliocene division. The sands are sometimes indurated, and nodules of small pyrite crystals and chalky lime are common. Small chert and quartz pebbles are also characteristic, and shell fragments continue as in the upper division. The Foraminifera are also the same as those found in the higher portion of the section, but are fewer in number and less varied as to species than in the upper beds. The thickness of this division is about 300 feet.

Lower division.—Red and blue gumbos are the dominant materials in the lower part of the Pliocene. These gumbos contain a varying amount of fine sand which is generally angular, some nodules of pyrite, many shell fragments, a few small, well-preserved shells, and a few Foraminifera, as in the division just above. *Chara* seeds are also found in these beds. The thickness of this division is 500 feet or more.

In the Pliocene beds encountered in the Associated Oil Company's Perry No. 1, there was found an *Orbitulina* of peculiar conical form, common to and characteristic of the Walnut clays.[1] This is interesting in that it may shed some light on the source of the material making up these sediments.

Miocene

The upper Miocene is found in the Roxana's Seaburn Nos. 1, 2, and 3. Although the Miocene and Pliocene formations on this dome are particularly difficult to divide because of the almost continuous conditions of shallow marine deposition which existed at this time, we are reasonably confident of the line of their separation, which has been established on both faunal and lithological grounds found to be constant in the wells mentioned. So far as we can ascertain, in one of the Roxana wells is the middle or lower Miocene present as it is found on the northeast side of the dome, where we are able to study these formations in some of the Freeport Sulphur Company's wells.

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[1] The Walnut clays are a member of the Fredericksburg group of the lower Cretaceous

Upper division.—An oyster-shell reef marks the upper extension of these beds. Heavy oyster-shell fragments also occur frequently and abundantly throughout the samples submitted from this division. Lithologically, the upper part of the Miocene is composed mainly of fine sands and highly arenaceous clays, some of which are micaceous. The sands are gray and tan in color, and the grains are generally angular. Nodules of pyrite and lime occur occasionally. Selenite crystals were common in the sands from this division in the Roxana Seaburn No. 3. A few reworked Cretaceous Foraminifera and a number of indigenous species occur in the samples. Some of the more common species present are: *Rotalia beccarii* Linn. var. (apparently confined to the Miocene), *Polystomella strattoni* n. sp.,* *Truncatulina* cf. *americana* Cush. var., *Textularia strattoni* n. sp.,* *Quinqueloculina* (several species). The thickness of the upper Miocene as found in the Roxana wells varies from 300 to 700 feet according to position on the dome.

Middle division.—Lithologically, the middle part of the Miocene is composed of beds of gray, sandy clays and sands with thin streaks of blue and brown gumbo. These beds contain no marine fossils of any kind. Lime and pyrite nodules are common. Beds of this description occupy the upper 400 feet of the middle Miocene as exposed in the Freeport's Seaburn No. 3. They are followed by a series of sediments that are largely non-fossiliferous, but include a few thin layers that contain some indigenous species of Foraminifera, Miocene varieties of *Rotalia beccarii* and *Polystomella*. Dark-blue and greenish-blue gumbos form the upper portion of these beds, and gray gumbos and packed sands the lower postion. Oyster-shell fragments were noted in one sample, and a small amount of glauconite in another. Because of the similarity of lithologic character, sparseness of fauna, and total absence of secondary foraminifers, we have included the above-described beds in the middle Miocene, giving that division a thickness of about 1,000 feet in this well. Throughout this division, the conditions of deposition were only rarely favorable to the existence of marine fossil faunas, and the source from which the sands were derived apparently did not include beds containing an abundance of Cretaceous Foraminifera such as form a part of the Miocene sediments in the Gulf Coast region.

In the Boggs No. 1, a horse tooth was secured from beds presumably of this division. The following determination was made by Dr. Chester Stock of the University of California: "An upper tooth of a horse which appears to me to represent some of the members of the *Merychippus* group. It is a long-crowned tooth, unique in its small size, but seems to possess all the general characteristics held by *Merychippus*. This genus is characteristic of the Miocene from a little below the middle of the period to the top. This particular specimen is comparable in size to some of the teeth of *Merychippus* that Dr. Buwalda collected in the Tehachapi and which belong apparently to the lower stage of the middle Miocene."

Lower division.—We believe that the introduction of the secondary material just mentioned above marks a change in the source of depositional material and possibly depositional conditions as well, and therefore place the top of this division at the first appearance of these forms below the non-fossiliferous zone. The divisions made here are rather arbitrary, and further study may prove that they are not so constant as we now suppose. The major portion of this division of the Miocene is composed of gray- and tan-colored sands. There are a few beds of blue, brown, and red gumbos, the major portion of which occur near the top of this division. The sand grains are generally very fine and usually even in size. Lime nodules and *Chara* fruit cases are found. Secondary Foraminifera occur abundantly throughout these beds, and a few indigenous forms are found at rare intervals. The thickness of this division in the Seaburn No. 3 is about 800 feet.

Oligocene

Catahoula?—At the base of the lower Miocene and for a few hundred feet directly overlying the Vicksburg Oligocene, we note a series of dark-gray gumbos and sands in each well from which we have good cores. These beds contain secondary Foraminifera and indigenous species like those mentioned above, some beds of oyster shells, and, as we approach the contact with the Vicksburg, a few species of Foraminifera common to the lower formation gradually appear, i.e., *Cristellaria*, *Orbitolina*, *Quinqueloculina*, *Nonionina*, and an occasional *Pulvinulina texana*.* There are two explanations for this condition: (1) either the Catahoula was entirely eroded before the deposition of lower Miocene sediments and the Vicksburg forms found here were reworked into these beds in lower Miocene times, or (2) these beds represent the gradual shallowing of the sea around this dome during Catahoula time while non-marine sediments were being deposited in the more northern area, there being consequently no sharp break between the definitely recognized Vicksburg below and the Miocene deposits above. We incline toward the latter view because (1) these beds are lithologically similar to the Vicksburg on this dome; (2) the species of Foraminifera common to both the true Vicksburg and this series of beds in question, instead of being worn species of abundant and heavy-shelled Vicksburg forms, as one would expect if they were reworked, are, on the contrary, fragile forms common but not dominant in the Vicksburg, and are also genera frequently found elsewhere in sandy, near-shore deposits. To be sure, reworked Vicksburg Foraminifera are found in Miocene sediments in the Humble's Brock No. 2 (see above), but the Miocene there is true marine Miocene, and not at all comparable to the beds here in question.

The thickness of this zone varies, but seems to average about 100 feet.

Vicksburg.—The presence of this formation was unknown in Texas until three years ago. It is now a well-known and easily recognized feature of the Gulf Coastal dome stratigraphy. In a recent paper by Applin, Ellisor, and Kniker[1] the Vicksburg has been subdivided into three parts on the basis of certain fairly constant faunal groups which take their names from the genera of Foraminifera found to be characteristic or dominant in each. These are the upper or *Discorbis* zone, middle or *Heterostegina* zone, and the lower or *Marginulina* zone.

Upper or *Discorbis* zone. Lithologically, this division of the Vicksburg here consists of a few upper beds of dark, olive-green shales followed below by dark-gray gumbos and greenish-gray, very fine-grained, marly sands. Nearly all the samples contain many indigenous species of Foraminifera and a few reworked Cretaceous forms. The *Discorbis* fauna is represented by very abundant and varied forms. This condition is true of Hoskins Mound as well, while on the majority of the coastal domes the number of species and individuals in the upper zone is not large, and the forms as a whole are not so well developed as in the older beds. This faunal assemblage is an index to conditions of deposition. Since nearly all the Foraminifera present are bottom-living forms, they may indicate that slightly deeper or quieter water conditions existed here than over the major portion of this area. The most common and abundant species in this zone here are:

Discorbis cf. *bertheloti* Cushman (form as figured by Cushman in *Prof. Paper 129E*, Pl. 32, Fig. 7)
Nonionina pratti n. sp.*
Polystomella striato-punctata (Fichtel and Moll) Parker and Jones n. var.
Polystomella macella Fichtel and Moll n. var. *dumblei** (without the keel)
Polystomella crispa (Linnaeus) Lamarck var. *seaburni* n. var.* (without a keel)
Polystomella texana n. sp.*
Pulvinulina texana n. sp.*
Pulvinulina texana n. sp. var. *strattoni* n. var.*
Rotalia beccarii Linnaeus
Cristellaria vicksburgensis Cushman
Cristellaria cf. *calcar* Linnaeus (as figured by Flint but without the spines)
Globigerina rubra d'Orbigny
Siphonina n. sp.
Textularia tolari n. sp.*
Nonionina scapha (Fichtel and Moll) Parker and Jones n. var (as figured by Cushman, *Prof. Paper 129E,* Pl. 23, Fig. 7)
Ehrenbergina glabrata Cushman
Quinqueloculina crassa d'Orbigny
Quinqueloculina glabrata Cushman
Textularia cf. *subhauerii* Cushman

Middle or *Heterostegina* zone. This division of the Vicksburg at West

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[1] "The Subsurface Stratigraphy of the Costal Plain of Texas and Louisiana," by Esther Richards Applin, Alva Ellisor, and Hedwig Kniker.

Columbia and Damon Mound is a highly fossiliferous limestone, but is here represented by a thin bed of marly, fine-grained sand which does not contain the *Heterostegina* which gives the division its name, but carries many specimens of *Amphistegina* n. sp. and other forms characteristic of this zone. The lower portion of this middle zone lacks the *Amphistegina* mentioned above, and shows a return of a fauna very similar to that of the *Discorbis* zone above. The most common and abundant species of Foraminifera present in this zone are:

Uvigerina byramensis Cushman
Amphistegina lessoni var. *texana* n. var.*
Pulvinulina texana n. sp.*
Cristellaria orbicularis d'Orbigny
Cristellaria rotulata Lamarck var.
Globigerina bulloides d'Orbigny
Globigerina conglobata Brady
Rotalia beccarii Linnaeus
Polymorphina byramensis Cushman
Cristellaria vicksburgensis Cushman
Truncatulina lobulata (Walker and Jacob) d'Orbigny
Truncatulina cf. *americana* (as figured by Cushman, *Prof. Paper 129E*, Pl. 20, Fig. 7)
Rotalia vicksburgensis Cushman
Polystomella crispa (Linnaeus) Lamarck var. *seaburni.* n. var.*
Textularia n. sp. (nearest to *T. hockleyi** of the Texas Jackson)
Quinqueloculina, several species

Lower or *Marginulina* zone. The lower part of the Vicksburg at Stratton Ridge differs markedly from the lower or *Marginulina* zone at West Columbia, Goose Creek, Damon Mound, and Pierce Junction. The genera and species of Foraminifera and the character of the sediments found on these other domes in this zone suggest that quiet and comparatively deep waters prevailed there. At Stratton Ridge, on the other hand, the lower zone of the Vicksburg is made up of a series of sands and sandy clays that frequently carry oyster and other shell fragments, and the Foraminifera present are only calcareous pseudomorphs of a variety of *Rotalia beccarii*, a form characteristic of shore and brackish-water deposits. One or two specimens of *Quinqueloculina* sp. which also occur in near-shore as well as deep-water deposits have been found. Beds belonging to this zone have been penetrated for about 200 feet, and it has been found that the foraminifera mentioned above occur only in the upper 100 feet. The lower beds are non-fossiliferous. No formation older than Vicksburg Oligocene has thus far been identified on this dome.

The total thickness of the Vicksburg Oligocene as we know it at Stratton Ridge is about 500 feet.

MACROSCOPIC FOSSILS

The following list of macroscopic fossils has been prepared from forms identified in samples received from various wells drilled at Stratton Ridge.

Castell Oil Company's Storrie No. 1

Feet

870–872....*Arca*, worn; in outline resembles *A. labiata* var., of Galveston deep well, upper Miocene; *Arca alcima* from Caloosahatchie beds has somewhat similar outline.

872–874....*Bittuim* sp., broken; may be *B. galvestonensis* Harris, of Galveston well, upper Miocene.
Phacoides crenulatus
Corbula sp., broken
Cerithium, fragment; may be *C. galvestonensis* Harris.

Freeport Sulphur Company's Seaburn No. 1

3,121........*Mactra lateralis*, Say, Galveston deep well 300–2,920
Mactra quadricentennialis Harris, Galveston deep well 2,123–2,873
Pecten sp.

3,241........*Nassa trivitatata* Say, Miocene and Pliocene Maryland
Olivella fragments
Turbinella sp. worn fragment
Pleurotoma cf. *calvertensis* Clark, Miocene of Maryland
Cylichna bidentata var. *galvestonensis* Harris, Galveston deep well 2,600–2,733
Chione cancellata fragment, Linné, Galveston deep well 1,550–2,871
Arca incongrua Say fragment, Galveston deep well 2,443–2,920
Mactra lateralis Say
Mactra quadricentennialis Harris
Strombina sp., not determined
Pecten fragment

3,245........*Arca* fragment
Chione cancellata fragment Linné
Natica cf. *eminuloides* Gabb, Galveston deep well 2,465–2,733
Corbula resembling most closely *C. seminula* Dall, Miocene
Mactra fragments
Terebra close to *gatunensis* Toula, middle and upper Miocene

3,352........*Chione*, middle Miocene form, fragment
Balanus sp.
Arca transversa Say, var. *busana* Harris, Galveston deep well, surface to 2,920
Pecten fragment

3,445........*Nassa acuta* Say var., Galveston deep well 440–2,871
Olivella fragment
Natica sp. fragment
Arca sp. fragment

	Natica eminuloides Gabb, young *Mactra quadricentennialis*, Harris *Dreissensia* sp.
3,670–3,739	*Pecten, Ostrea, Leda* fragments
3,810–3,862	*Terebra curvilineata* Dall, Miocene
4,051–4,060	*Chione, Leda, Dentalium* fragments, and fish teeth
4,060–4,177	*Leda* and *Natica* sp. fragments *Nassa* sp. like sp. in Tolar and Dannenbaum at 4,241 feet cf. *Nassa trivatiatoides* Whitfield
4,470–4,496	Fragment of a small *Cerithiopsis?*
4,554–4,571	Fragments of shells, chiefly *Ostrea*
4,714–4,720	Fragments of *Ostrea* shells

Freeport Sulphur Company's Tolar and Dannenbaum No. 9

3,234	*Mulinea lateralis* Say, like specimens from the Galveston deep well, 300–2,920, Miocene to Recent.
3,262	Shell fragments of *Ostrea, Balanus, Pecten, Chione cancellata?* and other undetermined bivalves.
3,312	Fragments of *Chione cancellata* Linné, Galveston deep well 1,550–2,871. Geologic range: upper Miocene of Galveston deep well and of South Carolina; Pliocene of Caloosahatchie; Pleistocene of North Carolina and the West Indies. *Mulinea lateralis* Say *Balanus* sp. undt. *Carcharias* sp.
3,818	*Chione cancellata* Linné Poorly preserved gastropod, possibly *Turritella* sp.
3,941	*Natica* sp. *Pecten* sp. undt. *Corbula inaequalis* Dall, Miocene *Arca* sp. undt. *Balanus* sp. *Chione* like form from the Oak Grove, middle Miocene of Florida *Nassa* sp. undt. *Leda* sp. undt. *Glycimeris* sp. undt. Otoliths of teleost fishes *Carcharias* sp.
4,078	*Chione* middle Miocene form[1] *Cerithiopsis* like form from Oak Grove, middle Miocene of Florida

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[1] Certain macroscopic Miocene fossils appear in this list below the depth at which the top of the Oligocene has been placed. In each case these fossils were found in cuttings and were undoubtedly washed down the hole. Cores showed only Oligocene forms with no Miocene present.

Balanus sp.
Ostrea sp.
Leda sp.
Arca sp.
4,087........*Chione* as above
Natica sp., broken
Oliva aff. reticularis Lam, Galveston deep well 2,158–2,920
Mulinea sp., broken
Otoliths of teleost fishes
4,115........*Cupularia umbellata*, lower Miocene to Recent, especially characteristic of the lower Miocene of the West Indies
Chione, as above
Nassa, like species from the Oak Grove, middle Miocene of Florida
Arca sp. fragment
Cylichna sp.
Mulinea lateralis? Say, broken
4,241–4,250..*Chione*, as above
Balanus sp.
Pecten sp.
Nassa sp., bearing a close resemblance to the form *Tritia trivitatoides* in the Miocene of New Jersey, but differing from it in a number of details
4,276–4,338..Fragments of *Chione*, middle Miocene form
Bryozoan, probably belonging to the genus *Semihaswellia*, species not described.

Humble Oil and Refining Company's Seaburn B-1

910–925....Fragment of *Eulima?* sp.
Planorbis ophis? Dall cf. *Teinostoma*, Miocene of Maryland; brackish-water Pliocene of Louisiana; cf. Fort Thompson species.
Two worn and broken specimens of coiled shell with low spine
1,100-1,137..*Nassa acuta* Say, upper Miocene to Pleistocene in Galveston deep well
1,194-1,224..*Nassa acuta* Say
Arca (*Plio* sp?) does not seem to be *A. ponderosa*
1,486–1,494..*Nassa? acuta* Say, broken specimen
Young of *Nassa acuta* or *Phos;* same form as at 547–557 in S. No. 1 Roxana, and at 1,500 in Perry No. 1
Low-spined smooth gastropod
1,567–1,582..*Phos* sp., same form as at 1,500 in Perry No. 1
1,646–1,661..*Mulinea sapotilla* Dall, brackish-water Pliocene of Louisiana
Phacoides crenulatus Conrad

1,661–1,670. . *Mulinea lateralis*, young
Paludestrina aff. aldrichi Dall, brackish-water Pliocene of Louisiana

Roxana Petroleum Company's Seaburn No. 1

449–487. . . . *Paludestrina* sp. cf. *Syrnola caloosaensis* Dall, upper Miocene—Pliocene of Florida; not a *Syrnola*
Paludestrina cf. *aldrichi* Dall fragment, brackish-water Pliocene from near Alexandria, Louisiana
Paludestrina? n. sp.? anterior portion more angulated than any species from brackish-water Pliocene of Louisiana
Spisula cf. *subparilis,* Conrad, Tertiary of Florida, upper Miocene of Maryland
547–557. . . . Fish tooth?
Phos? sp. cf. form in Avoca well called young of *Nassa acuta;* also occurs at 1,500 in Perry No. 1.

Roxana Petroleum Company's Seaburn No. 2

382–413. . . . *Rangia* sp., broken.
Mulinea, probably *lateralis,* two broken specimens; this species ranges from Miocene to Recent.

Roxana Petroleum Company's Seaburn No. 3

409–530. . . . *Nassa acuta* Say; Harris gives the range as upper Miocene to Pleistocene.
Scala cf. *sayana* Dall, from the upper Miocene of Maryland; Dall lists this species from the Pliocene of Caloosahatchie and the Recent from Texas to Key West.
1,557–1,580. . *Mulinea* sp., broken.
Corbula sp., very close to species from Oak Grove and Galveston well (*C swiftiana?);* Harris gives range of the Galveston well species as upper Miocene to Pleistocene; cf. *C. sphenia* (Chapola).
Phacoides crenulatus Conrad; Harris gives the range of this species in the Galveston well species as upper Miocene, but the Pleistocene species from West Palm Beach is the same.
Gemma n. sp. cf. *G. purpurea* var. *totteni* Dall
1,633–1,644. . *Mulinea* sp., broken
1,770–1,796. . *Mulinea* cf. *sapotilla* Dall, from brackish-water Pliocene of Louisiana, Bryozoans, *Membranopora,* possibly *M. flabellata,* upper Miocene to Recent
1,899–1,930. . *Corbula* sp. from 1,557 to 1,580, range upper Miocene to Pleistocene
2,185–2,189. . *Corbula* sp., broken; does not appear to be the same as *Corbula* at 1,557 or 1,899.

GEOLOGIC HISTORY OF THE DOME

Paleontological study has shown that during the earliest part of Oligocene time the lithological and faunal characteristics of the sediments at West Columbia, Goose Creek, Damon Mound, and Pierce Junction suggest prevailing quiet and comparatively deep waters. At Stratton Ridge, to the east and south of these domes, the lowest Oligocene sediments are lithologically and faunally characteristic of near-shore and brackish-water conditions. This suggests that perhaps some uplift took place in this region during or just prior to the earliest Oligocene.

The top of the salt core at Stratton Ridge is about 3,000 feet above the original position of the now upwarded Oligocene, and the sediments of this and the Miocene periods are shown to be sharply upthrust and steeply tilted close to the sides of the salt mass, at least on the northeast side of the dome, where we have the most complete information. The Pliocene sediments overlie the Miocene beds unconformably near the salt core. No Miocene sediments pass over the top of the salt, nor do the lowest Pliocene. The Miocene-Pliocene contact shows an uplift of about 300 feet in the Roxana Seaburn Nos. 1, 2, and 3, while the overlying Pliocene beds show less and apparently lie nearly flat across the top of the salt. It therefore seems probable that the intrusion of the salt and the period of maximum deformation came between the Oligocene and early Pliocene. Some minor upthrust of the salt evidently has taken place since the Pliocene.

OIL AND GAS

The indications which led to drilling at Stratton Ridge were gas seeps in a water well near Stubblefield Lake, and the topographic expression of the salt dome.

Shows of oil and gas were encountered in thin sands above the gypsum anhydrite cap in some of the Freeport Sulphur Company's wells drilled on the top of the salt. The Castell Oil Company's Storrie No. 1 had a strong gas blow-out at about 750 feet, but the flow was not lasting. There is no record of any showing of oil or gas in the Roxana wells. No commercial production was ever developed on the top of the salt, and the wells drilled there have tested the cap and the sands above with sufficient thoroughness to prove further prospecting for cap-rock oil useless.

Four of the wells drilled on the northeast side of the dome have encountered good indications of oil in the lateral sands. These wells are the Freeport Sulphur Company's Tolar and Dannenbaum Nos. 8, 9, and 11 and C. C. Cannan's Boggs No. 2. In the Tolar and Dannenbaum No. 8, oil and gas were found at 3,082–3,142 feet. This well was abandoned at the latter depth. In No. 9, the record gives several oil and gas shows between the depths of 3,100 and 4,300 feet. Twenty feet of sand logged from 4,344 to 4,364 feet at the bottom of the hole produced 28° B. oil for a short time and then sanded up. No. 11 had showings of oil from 3,501 to 3,512 feet and pumps about 75 barrels a week from sand and shale at a depth of 4,249–4,386 feet, but the well is not pumped regularly. C. C. Cannan's Boggs No. 2, the latest well to encounter oil, produced 1,500 to 2,000 barrels a day for a few days from a sand found at 4,274–4,285 feet and is now being pumped. Boggs No. 1 reported oil shows at the following depths: 3,196–3,226 feet, 3,550–3,565 feet, and 4,560–4,575 feet.

Shows of oil and gas were found in the Freeport's Tolar and Dannenbaum No. 10 from 2,218 to 2,430 feet and from 2,554 to 2,602 feet. Gas shows in the Freeport's Seaburn No. 1 occurred at depths of about 3,600, 4,050, 4,250, and 4,550 feet. A show of oil and gas was found in this well at 4,697–4,765 feet. In Farish's Seaburn No. 2, oil is reported from 1,920 to 1,950 feet, and gas from 2,115 to 2,150 feet. It is not known whether oil and gas shows were encountered in any of the Humble's wells drilled on this dome; the records do not show any.

Cores from Tolar and Dannenbaum No. 9 at 4,357 and from Tolar and Dannenbaum No. 11 at 4,371 show the sand to be fine, hard, and closely cemented, probably on account of compression of the sediments accompanying the upthrust of the salt mass.

ACKNOWLEDGMENTS

In presenting this paper, the writer wishes to acknowledge his indebtedness to the Freeport Sulphur Company for permission to use the paleontological information obtained from well samples fur-

LIST OF WELLS DRILLED ON THE STRATTON RIDGE SALT DOME

Company	Lease	Well No.	Total Depth Feet	Remarks
Freeport Sulphur Company	Tolar and Dannenbaum	1	1,312	Cap at 1,084 feet. Salt at 1,308 feet
Freeport Sulphur Company	Tolar and Dannenbaum	2	2,102	Cap at 1,212 feet. Salt at 1,316 feet
Freeport Sulphur Company	Tolar and Dannenbaum	3	1,200	Cap at 1,192 feet. Oil show 1,154–1,173 feet
Freeport Sulphur Company	Tolar and Dannenbaum	4	1,326	Cap at 1,238 feet. Salt at 1,319 feet
Freeport Sulphur Company	Tolar and Dannenbaum	5	1,270	Cap at 1,258 feet. Oil show 1,166 feet
Freeport Sulphur Company	Tolar and Dannenbaum	6	1,345	Cap at 1,338 feet. Gas at 1,153 feet
Freeport Sulphur Company	Tolar and Dannenbaum	7	2,475	Junked
Freeport Sulphur Company	Tolar and Dannenbaum	8	3,142	Junked. Oil and gase shows
Freeport Sulphur Company	Tolar and Dannenbaum	9	4,364	Oil sand 4,344–4,364 feet
Freeport Sulphur Company	Tolar and Dannenbaum	10	3,255	Cap at 2,617 feet. Salt at 2,633 feet
Freeport Sulphur Company	Tolar and Dannenbaum	11	4,386	Oil sand 4,249–4,386 feet. Pumps 75 bbls.
Freeport Sulphur Company	Tolar and Dannenbaum	12	....	Drilling
Freeport Sulphur Company	Seaburn	1	4,765	Salt at 4,765 feet. Oil and gas showsepwkeer
Freeport Sulphur Company	Seaburn	2	2,573	Cap at 2,380 feet. Salt at 2,473 feet
Freeport Sulphur Company	Seaburn	3	4,442	
Roxana Petroleum Corporation	Seaburn	1	1,686	Cap at 1,655 feet
Roxana Petroleum Corporation	Seaburn	2	1,955	Cap at 1,851 feet
Roxana Petroleum Corporation	Seaburn	3	2,522	Cap at 2,490 feet
Roxana Petroleum Corporation	Seaburn	4	1,400	Cap at 1,003 feet. Salt at 1,334 feet
Humble Oil and Refining Company	Seaburn	B-1	3,635	
Humble Oil and Refining Company	Seaburn	B-2	1,799	Cap at 1,609 feet. Gas show 1,650–1,655 feet
Humble Oil and Refining Company	Seaburn	B-3	3,204	Junked
Humble Oil and Refining Company	Seaburn	5	1,121	Cap at 1,045 feet
Humble Oil and Refining Company	Seaburn	6	3,610?	
Humble Oil and Refining Company	Seaburn	7	3,458	
Humble Oil and Refining Company	Brock	1	1,471	Cap at 1,302 feet. Salt at 1,311 feet
Humble Oil and Refining Company	Brock	2	2,904	Junked
Humble Oil and Refining Company	Shea-Storrie	1	4,086	
Farish et al	Tolar and Dannenbaum	1	2,082	
Farish et al	Seaburn	1	2,094	
Farish et al	Seaburn	2	2,758	Abandoned in "sandy gyp." Oil and gas show 1,920–1,950 feet and 2,115–2,150 feet

Dannenbaum	Stratton	1	1,058	
Dannenbaum	Stratton	2	854	Gas show 839–842 feet
Castell	Storrie	1	1,314	Cap at 882 feet. Gas blow-out 750 feet
C. C. Cannan	Boggs	1	4,575	Oil and gas shows
C. C. Cannan	Boggs	2	4,287	Oil at 4,274–4,285 feet
Empire Gas and Fuel Company	Wilson	1	4,671	
The Texas Company	Cochran and McClure	1	2,340	Junked
The Texas Company	Cochran and McClure	2	3,100	
Associated Oil Company	H. B. Perry	1	....	Drilling

nished by them, and also for maps, well logs, and other data; to Mr. William Kennedy, consulting geologist for the Freeport Sulphur Company, for much information regarding the general structural aspects of the dome; to the Humble Oil and Refining Company and the Roxana Petroleum Corporation for furnishing samples obtained from several of their wells, and for permission to use the paleontological data obtained from the samples. The writer is particularly indebted to the paleontological department of the Rio Bravo Oil Company for their generous work in preparing the paleontological data used in this report.

THE BRYAN HEIGHTS SALT DOME, BRAZORIA COUNTY, TEXAS

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ABSTRACT

The Bryan Heights salt dome is located in southern Brazoria County, Texas, near the mouth of Brazos River and nearly due south of Houston. It is marked topographically by a low mound which rises about 25 feet above sea-level. The top of the salt is encountered at an average depth of about 1,100 feet. Formations of Quaternary and later Tertiary age overlie the dome, and as in the case of other Gulf Coast domes there are more or less steeply inclined Tertiary rocks surrounding the salt core. A sulphur-bearing cap rock is of chief economic importance, sulphur being mined by the Frasch hot-water process from depths of about 700 to 900 feet below the surface. Some deep drilling, to depths of more than 3,500 feet, has been undertaken on the flanks of the dome, but no commercial oil or gas has been encountered.

INTRODUCTION

Bryan Mound lies in the southern portion of Brazoria County, Texas, 3 miles south of Freeport and not more than 1 mile from the coast. The region around the mound is low, flat, marshy country of recent material and not more than 2 or 3 feet above tide-level. The greater portion is occupied by shallow lagoons, some of which are dry at low tide. The mound itself rises out of these marshes to an elevation of about 23 feet and covers an area of approximately 300 acres. Since operations have been in progress the surface of the mound has sunk about 2 feet. This subsidence has taken place mostly in the areas where numerous wells have been operated.

HISTORY

Attention was first called to Bryan Mound by S. F. Peckham in a report on "Petroleum," in the *Tenth Census*, 1880, where he says, "near the mouth of the Brazos River and in other parts of Texas, beds of asphaltum occur, evidently resulting from the decomposition of petroleum, but so far as I have been able to learn, they have no commercial value." He indicated the position of the mound on his map as a point at which petroleum and asphalt occurred. This statement may have had reference to seawax which is occasionally found on the neighboring coast, or to minute grains of what appears to be the same material occurring in the soil at different places. During the oil excitement of the year 1901, the J. M. Guffey Petroleum Company obtained a number of leases around and on the mound and commenced drilling. At a depth of about 900 feet the first well encountered gas and had an estimated daily flow of 6,000,000 cubic feet, mostly hydrogen sulphide. Attempts to control the gas flow were unsuccessful and the well was abandoned. Another well was drilled by the same company, and as this also proved valueless the field was abandoned.

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[1] Chief geologist, Lone Star Gas Company, Dallas, Tex.

Other parties acquired the leases subsequently and attempted to drill for oil, but in each case the operations proved fruitless, either on account of the pressure of water or gas, although the gas pressure had largely fallen off. Seven wells were drilled in this region prior to 1904, some of them being carried to depths exceeding 1,000 feet. During the course of this work the drill is reported to have passed through large deposits of lime and gypsum showing considerable quantities of sulphur, the sulphur being scattered mostly throughout the gypsum, though some was with the lime. These materials were encountered between 700 and 900 feet beneath the surface.

During these early years of exploration of the coastal regions, petroleum was the only product desired, all other minerals being passed almost unnoticed. With the failure of petroleum production, Bryan Mound was abandoned until some time in 1906, when H. T. Staiti, P. M. Granbury, L. Bryan, and associates incorporated a company for the purpose of prospecting this territory for sulphur. The company held leases on the McNeil and Arnold tracts, including the greater portion of the mound, and carried out some exploration by drilling. On the strength of the showing of sulphur obtained arrangements for sale of the property were made, but because proposed methods of obtaining the sulphur infringed patents on the Frasch process, the sale finally fell through. Additional prospecting was carried on, however, and in all some twenty-seven test wells were drilled. It was asserted that sulphur in greater or less quantities had been found in every one of these test holes, and that about 300 acres had been proved to be profitably sulphur-bearing.

About 1912, the property passed into the hands of Mr. Swenson and associates. These gentlemen, after drilling a number of prospect holes in which sulphur was found in fair quantities, installed a plant at a cost of about $200,000 for the purpose of obtaining the sulphur and preparing it for market. This plant was similar to that of the Union Sulphur Company at Sulphur Mine in Louisiana, in employing what is known as the hot water process. During the early portion of December, 1912, sulphur was brought up for a few days, but owing to slight defects in the machinery, work ceased for some months. During 1914 or 1915, work was resumed with a greatly enlarged plant, and since that time operations may be said to have been continuous.

TOPOGRAPHY

Bryan Mound consists of a slightly elevated mound having a slight slope toward the east and southeast, the highest portion of the surface, about 24 feet above sea-level, lying near the western side (Fig 1). The easterly inclination of the surface coincides with that of the underlying beds; thus the top of the salt, although not very regular, shows a descent from an average depth of 1,138 feet along the western side to 1,152 feet along the eastern side of the mound.

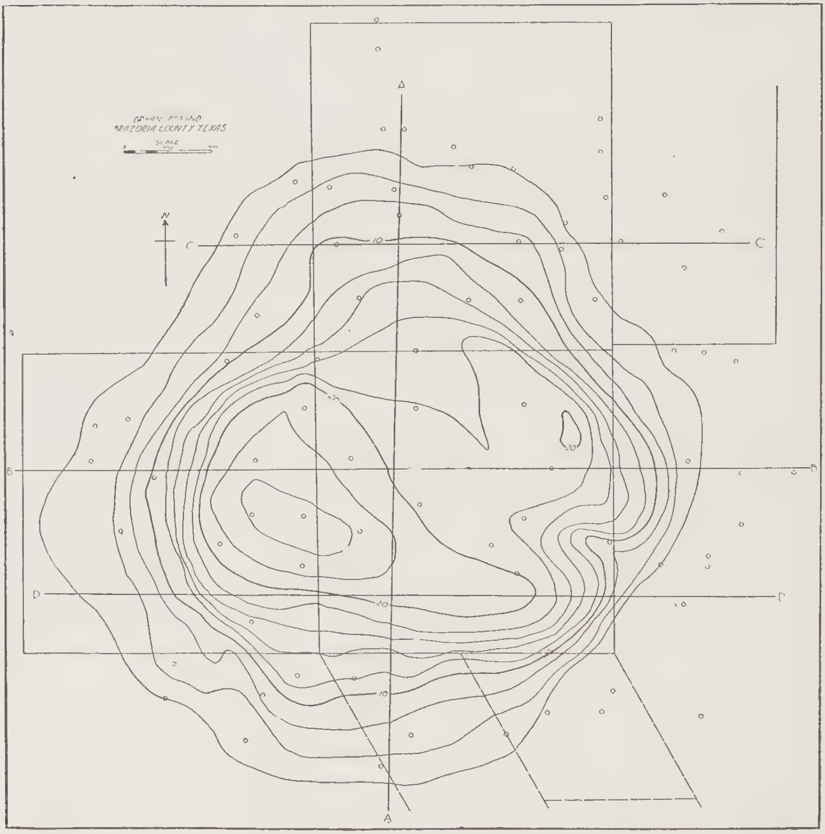

FIG. 1.—Surface topography of Bryan Mound, Texas. Contour interval 2 feet

This is a difference of only 44 feet in a distance of approximately 5,000 feet, a slope of 46 feet per mile. The gypsum- and sulphur-bearing formations show a similar easterly slope of 56 feet in the same distance, while the overlying limestones show a slope of 89 feet, or a dip of 94 feet per mile to the southeast. This is nearly four times the average slope of the surface.

GEOLOGY

Considered alone, the geology of Bryan Mound is comparatively simple, but in connection with its surroundings this mound presents a somewhat different problem. The rocks above the cap include about 300 feet of Recent and Pleistocene and Beaumont clays, and approximately 400–500 feet of sands and clays carrying Upper Miocene fossils. Since Pliocene formations occur along the flanks of some of the other mounds, notably at Stratton Ridge and Hoskins Mound, it is very probable that formations of this age also occur upon and around Bryan Mound, although nothing very definite is known about them.

Along the northern edge of the mound the country slopes somewhat gently toward the north for a short distance and drilling throughout that region has been carried down to depths ranging from 1,750 near Hawkinsville to 3,507 feet on the Bryan lease about 4 miles northwest of the mound. In another well drilled by the Chester Oil Company, about ½ mile east of the dome, the drill reached a depth of 2,911 feet. The Freeport Sulphur Company wells on the Poole & McNeil leases were carried down to depths of 3,000 feet.

Between West Columbia on the north and Bryan Mound on the south, there is evidently a trough about 3,000 to 3,500 feet deep. The materials filling this trough consist of clays, sands, shales, and gumbos with gravel and bowlders. From the presence of dark-green shale and sandy shale showing oil from 2,554 feet in the Chester well, the writer considers the lowest 257 feet as Fleming, and the uppermost 575 feet as belonging to the Beaumont clays. Some 1,400 feet of the intervening strata may be placed in the Lafayette and the rest in either the Lagarto or Lapara or both.

STRUCTURE

Dumble[1] has said that the Coastal Plain during Tertiary times was subject to oscillations which marked the dying out of vulcanism. Pliocene or pre-Pleistocene erosion acting in connection with flexures produced at the time left a number of hills and ridges scattered over the coastal strip which during the Pleistocene submergence were mostly covered by coastal clays.

[1] *Trans. Amer. Inst. of Min. Eng.*, Vol. 31, p. 1030.

Since no particular attention was paid to structural conditions when drilling was carried on, there is unfortunately no definite knowledge concerning underground conditions above the sulphur-bearing beds, except that Upper Miocene and Pleistocene formations are present. However, since the Pliocene, Miocene, and Oligocene are present at Stratton Ridge, the salt dome nearest to Bryan, it is probable that these formations exist also at Bryan Mound, either above or around the salt core (Fig. 2).[1]

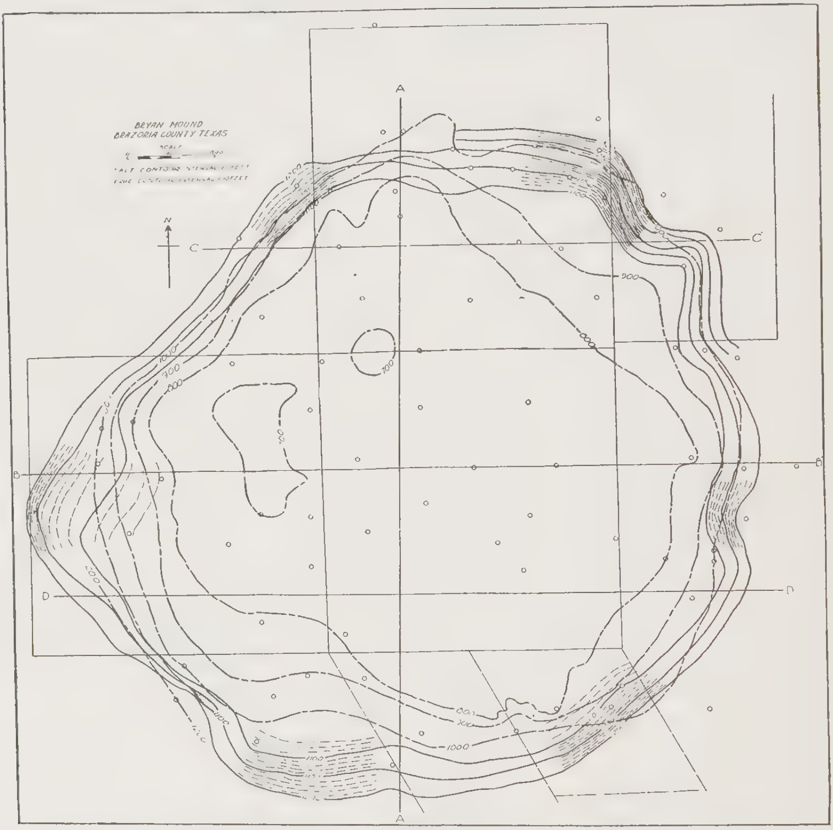

FIG. 2.—Topography of the top of the cap rock and the top of the salt in the Bryan Heights salt dome.

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[1] Since this article was written, two wells have been drilled near the foot of the mound on the north side. The first, No. 616, was drilled to a depth of 1,956 feet and the second, No. 617, to a little below 2,550. No examinations were made of material

The structure of this mound is essentially similar to most of the coastal mounds. A series of sands, clays, and gumbos occurs down to about 700 feet; limestones, gumbos, and shales extend to 760 feet; to 1,090 feet there appears a zone of very porous, cavernous limestones and gypsums mixed with sulphur and carrying large quantities of hot sulphur water and hydrogen sulphide; below this and above the salt, there appears to be a series of limestones carrying

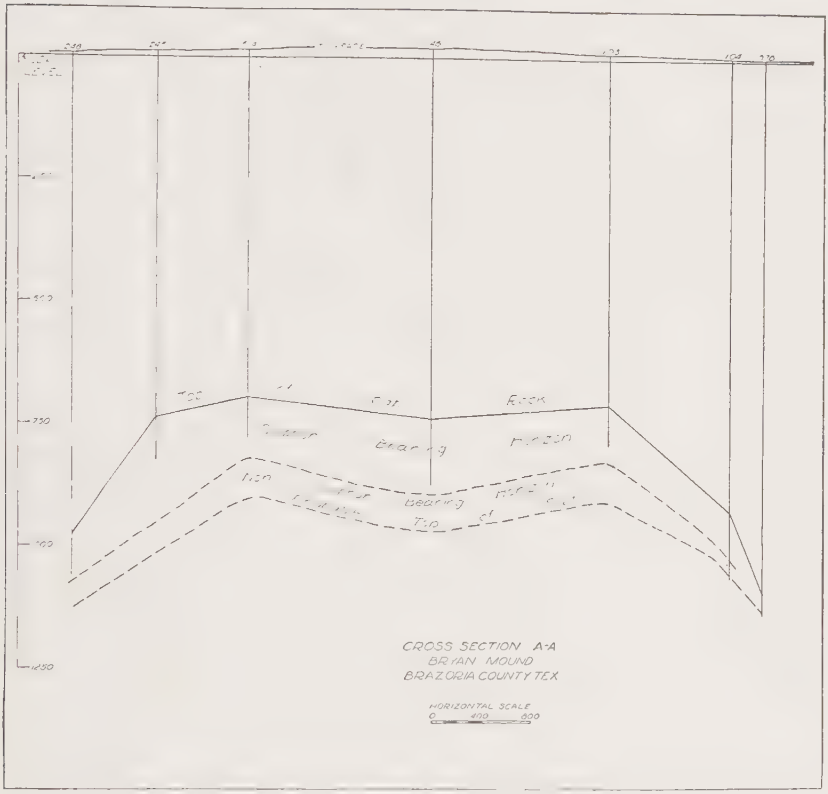

FIG. 3.—Cross-section from north to south across Bryan Heights salt dome. For location see Fig. 1.

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obtained from well No. 616, but numerous limestones were passed through from 1,626 feet to bottom. The cuttings from well No. 617 were examined by Mrs. E. R. Applin and Miss G. Newman of the Rio Bravo Oil Company and these showed the presence of both Miocene and Oligocene. This well also encountered limestones from 1,795 feet to bottom.

iron pyrite, gypsum, and sandstone, approximately 80 feet in thickness, but without sulphur. The salt makes its first appearance at depths between 1,000 and 1,100 feet.

Kirby Thomas, who examined a core from Reed well No. 3 drilled by the Gulf Development Company near the western margin of the dome, reports:

> This core shows 175 feet of sulphur formation of which 35 feet is limestone and gypsum showing sulphur estimated at less than 10 per cent, and 85 feet of gypsum and limestone with 10 to 50 per cent of sulphur; 54 feet of the core is missing, which indicates that the soft friable sulphur and gypsum in this much of the hole did not core. I examined all the 120 feet of core inch by inch and made an estimate that more than one-third would run 30 per cent or better, and that about 50 feet would run to about 10 per cent or better; about 20 feet was barren limestone.[1]

The beds encountered in a well drilled in the marsh northwest of the hill (Fig. 3) included heavy beds of clay of the Beaumont type and beds of quicksand. At 370 feet there was a small showing of gas, and fresh water occurs in a sand at the depth of 645 feet. *Gnathadon cuneatus* shells are common to a depth of 350 feet, but become scarce below that depth, although a few were found at a depth of 730 feet. Large quantities of wood in a carbonized condition are found at depths between 370 and 730 feet, but mostly from around 600 feet.

Dall reports that the fossils found in this mound between 649 and 668 feet are not older than Upper Miocene. In well No. 518 the following fossils identified by G. D. Harris were found between 292 and 300 feet: *Nassa acuta*, *Tornatina canaliculata*, *Arca transversa*, *Mulinia lateralis*, *Polynices duplicatus* (immature), *Terebra dislocata*, *Corbula contracta*, *Seila adamsi*, *Lucina amianta*, *Columbella obisa*, *Arca ponderosa* (immature). According to Harris, these are of Pleistocene age.

The sulphur-bearing beds consist mostly of gypsum in various forms from amorphous to crystalline. Selenite occurs as crystals and, less commonly, as thin plates or flakes. The amorphous gypsum is usually in a granular form and very intimately mixed with carbonate of lime. An examination of many of the cores from different wells shows the amorphous gypsum to be badly broken with very close fractures extending in various directions throughout the core. These, although scarcely perceptible to the eye, all contain thin films of sulphur. It may be remarked that what has usually been considered as gypsum, closely associated and intermixed with the sulphur in this field, is not pure gypsum, since when treated with hydrochloric acid more than half of the rock goes off in the form of carbonate of lime, leaving a residue of gypsum in the form of a soft, white, pasty mass. At Hoskins Mound, it is claimed that at about the depth of 681 to 710 feet the drill passed through a soft, sticky, white clay, becoming chalky when dry. That description answers the residual mass left in the Bryan Heights sulphur-bearing beds after the removal of the lime and sulphur. The gypsum beds carry masses or thin deposits of black carbonaceous shales at somewhat irregular intervals and at different depths in the different wells. They also carry barite in small quantity and mostly in the form of rounded or water-worn nodules, some of which are as much as 3 inches in length and nearly 1 inch in thickness.

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[1] *Mineral Resources of U. S., 1912*, Part 2, p. 936.

The structure of these sulphur-bearing deposits is not regular (Fig. 4). In some places, the selenite crystals stand at a high angle and at others lie in thin sheets almost flat; the granular portion of the deposits often shows threadlike columns standing perpendicular to the core of the well and again lying as if they had settled down quietly. The selenites sometimes show twinning, but this is not very frequent. The deposits might in some places be considered vesicular on account of the numerous cavities found interspersed between the thin layers of gypsum. In addition, numerous large channels are found in various wells. Neither of these cavernous conditions are universal throughout the mound.

The sulphur itself is very irregularly distributed throughout the beds. It is found often in very small crystals, even microscopic in size, but frequently in the form of larger masses of crystalline sulphur and as pipes extending upward through the beds. The sulphur is also found in the shape of stalactites in the openings made by the acidulated water or as thin plates lining the cavities made by the waters. While the sulphur sometimes appears as translucent crystals of a bright or pale amber color, the greater portion is amorphous, showing a light-yellow or canary color. In whatever manner it may occur, it is always irregularly distributed and no two wells are alike as to content.

Immediately underlying the sulphur-bearing deposits and between these and the salt, there is a series of deposits consisting of lime, anhydrite, and gypsum, with some gumbos and sand. These are reported to have an average thickness of about 80 feet, but it is doubtful whether this thickness can be found anywhere upon the surface of the mound itself. Limestone appears to be the prevailing material in this series. Across the northern end of the mound, a fine, loose sand appears in contact with the salt, and the same appears along the eastern side where 140 feet of mixed sand and salt are found in the bottom of well No. 586 (Fig. 5.)

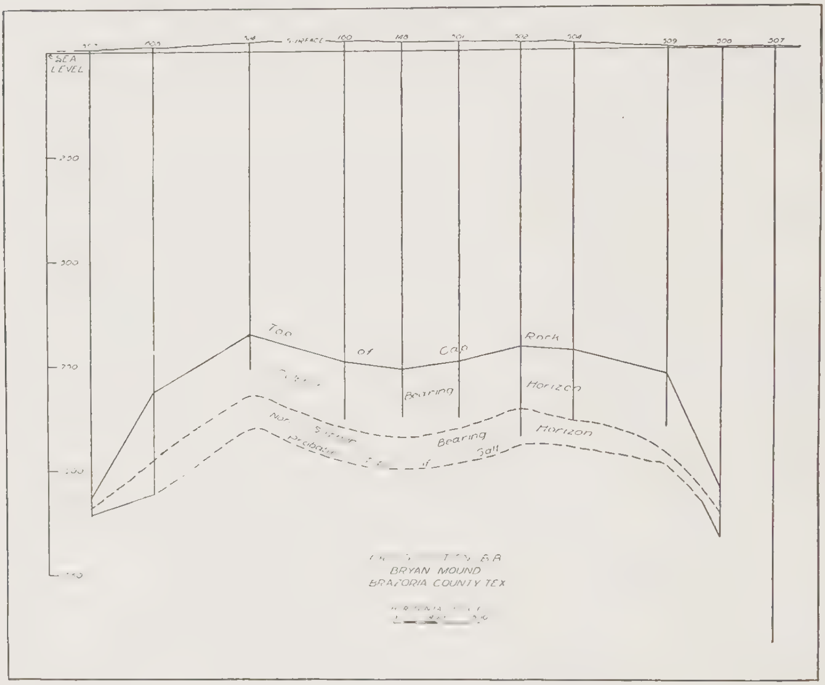

FIG. 4.—Cross-section from east to west across central part of Bryan Heights salt dome. For location see Fig. 1.

On the western side of the mound many of the wells show the lime resting directly upon the salt. The barren zone between the sulphur-bearing horizon and the salt core of the mound is not constant in its character. Sand is frequently found in immediate contact with the surface of the salt, and in several holes gumbo occupies the zone of the gypsum or lime.

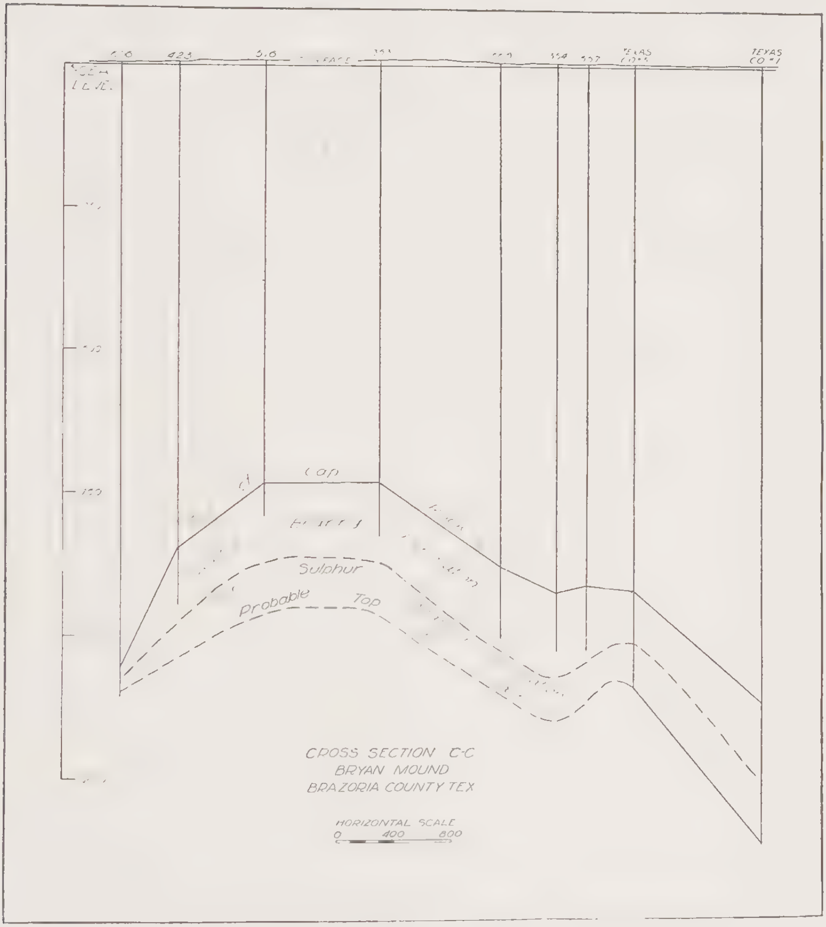

FIG. 5.—Cross-section from east to west across north part of the Bryan Heights salt dome. For location see Fig. 1.

The following combination log of well shows the general character and arrangement of rocks at this mound:

	Depth in Feet	
Sands, clays, and gumbo	0	680
Blue limestone and gumbo with showing of oil	680	762
Gypsum with sulphur, cavernous with showings of gas and large quantities of black sulphur water	762	791
Gypsum and sulphur, about 75 per cent of the sulphur in the form of flakes; contains gas and black sulphur water	791	856
Gypsum and sulphur with gas	856	1,090
Soft formation, gypsum (anhydrite) and sandstone with some lime, no sulphur	1,090	1,112
Rock salt	1,112	1,160 plus

SALT

In keeping with the other coastal domes, salt forms the base of Bryan Mound. The thickness and general character of this salt deposit are unknown, since none of the drilling has gone more than 150 to 200 feet into it. One of the wells records the salt as being stratified, but that may be considered doubtful even though the core appeared to verify this statement.

Structurally, the salt is separated from the overlying sulphur-bearing gypsum by a series of deposits made up of hard, dark-colored gypsum (probably anhydrite), clays, dark shales, and in several wells by heavy deposits of sand, many of which appear to be intermingled with grains and crystals of salt. In some of the wells limestones lie directly upon the salt.

Although the upper surface of the salt shows a general slope from west to east, this gradient is very irregular as if the salt had been subjected to erosion before being covered by the overlying deposits. This condition is especially notable in the wells in which the sand was found on top of the salt. This sand with its associated salt grains lies in a pit or depression worn in the upper surface of the salt. The shales found in contact with the salt appear to occupy a similar position. Around the edge of the dome the cap rock drops down to the edge of the salt. Where the salt stops, this so-called cap-rock also stops (Fig. 6).

Around the west, south, and east sides, the salt has extremely steep slopes, in some places almost perpendicular. Along the western side this slope, although very steep, is greatly modified, but the strong slopes are again seen on the southeastern and northeastern sides. The sides of the dome as well as the top seem to have been subjected to erosion before being covered up. This condition may, however, be due to an irregular uplifting of the salt core and an extrusion of the salt into softer deposits along the sides of the dome. A similar condition exists at Stratton Ridge and possibly at Hoskins Mound. There is a possibility that a fault extends along the southern exposures of these three mounds and that this faulting is in a great measure responsible for the presence of the salt.

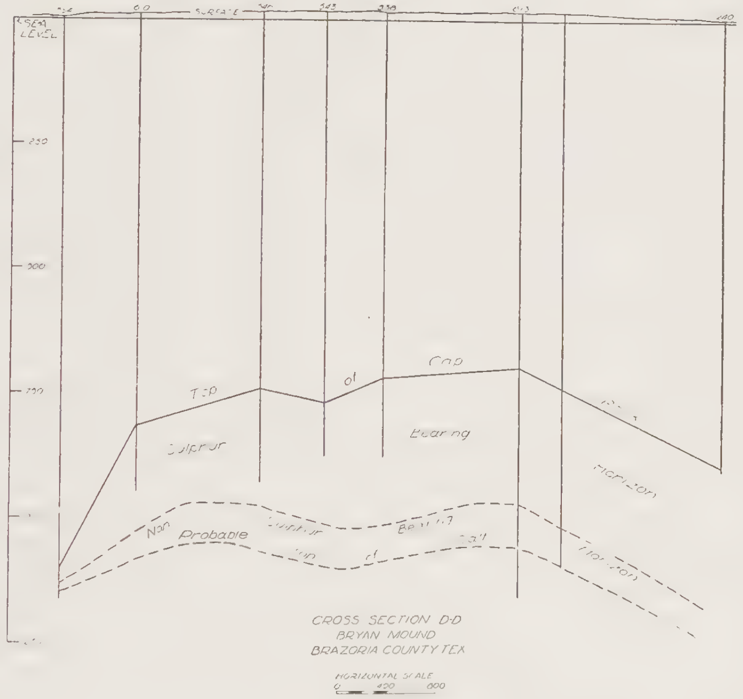

FIG. 6.—Cross-section from east to west across south part of Bryan Heights salt dome. For location see Fig. 1.

The salt has been subjected to considerable pressure. We know from the general geologic conditions of the coastal country that there has been great movement at different periods. It is probable that when pressure was exerted by these movements the areal extent of the original salt deposit was greatly reduced and the salt itself forced upward into the form of a mound as we now find it. The movements were repeated several times and the salt in all probability was subjected to pressure every time these earth movements occurred. The condition of the sides and upper surface of the salt accord with this view.

MINING METHODS

Economically, Bryan Mound may be considered only as a source of sulphur. The sulphur is recovered by the Frasch process, which was first utilized at the Union Sulphur Company's mine in Louisiana and has been described as follows:

> In drilling these wells, the rotary rigs so common in the Gulf Coast oil fields are used. A casing is set in the well down to the cap rock which forms the top of the sulphur-bearing layer. Inside of this casing is set a 6-inch pipe perforated at the lower portion. Within the 6-inch pipe is a 3-inch galvanized iron pipe also perforated near the bottom and finally within that is a 1-inch galvanized iron pipe.
>
> On operating the well hot water under a pressure of 200 to 300 pounds per square inch and at a temperature of 330 degrees F. is pumped down through the outer pipe and discharged into the porous sulphur-bearing calcite near the bottom of the strata. Similarly, hot water is forced down the 3-inch pipe and discharged into the porous formation through the perforated lower portion of the pipe. These two streams of hot water, at a temperature considerably above the melting point of sulphur (sulphur melts at about 240 degrees F.), gradually heat up the surrounding rock, melt the sulphur and its flows down into the heated area around the bottom of the well. After a sufficient heating has taken place the pumping of water down through the 3-inch pipe is discontinued and the melted sulphur rises in it. Air under high pressure is then pumped down the 1-inch pipe and the melted sulphur which has accumulated in the 3-inch pipe is lifted to the surface of the ground. This pumping of the melted sulphur by compressed air operates on the same principle as the air lift so commonly used for pumping water. The pressure of air required may run as high as 650 or 700 pounds per square inch in starting, but after the flow of sulphur is established the pressure drops off somewhat. The quantity of water required per ton of sulphur varies greatly with local conditions immediately surrounding the well.

The enormous quantity of water used in extracting the sulphur together with what we may consider as native water would in a very short time so flood the mound as to render it practically impossible to mine. As a relief, however, to this condition many of the old wells, from which all the sulphur available has been extracted, are utilized for the pumping of all surplus water. These wells are scattered throughout the mound and by this means the water found in the mound is kept under control.

BIG HILL SALT DOME, MATAGORDA COUNTY, TEXAS

ALBERT G. WOLF
Gulf, Texas

ABSTRACT

Big Hill, Matagorda, is a characteristic Gulf Coast salt dome and has a distinct salt-dome mound, a subcircular salt core intruded into Tertiary sediments and a thick cap on the top of the salt. The cap contains an extensive and important deposit of sulphur. The cap is composed of (*a*) a "barren cap" of limestone above, (*b*) the sulphur-bearing zone composed chiefly of limestone and grading below into (*c*) a thick deposit of barren anhydrite. The sulphur is secondary and later than the limestone and anhydrite. The sulphur is mined by the Frasch process in which superheated water is pumped down through a drilled well; the melted sulphur is collected at the bottom of the well and pumped to the surface by an air lift. A review is given of the possible reactions for the formation of the sulphur. On account of the lack of extensive drilling, little is known about flanks of the dome, a small amount of oil was produced in the early days, mostly from the top of the cap.

INTRODUCTION

Big Hill, Matagorda County, Texas, is 1 mile from the shore of Matagorda Bay, about midway on the county's coast line, and 20 miles south-southeast of Bay City. A branch line of the Gulf, Colorado and Santa Fe Railway extends to the sulphur mine of the Texas Gulf Sulphur Company now operating there.

This dome has been little prospected for petroleum; few deep holes have been drilled as compared with the other coastal domes, and little paleontological work has been done on the deeper sediments. The age of the dome and the stratigraphy of the deeper surrounding sediments, therefore, are correspondingly somewhat uncertain. Big Hill (now known also as Gulf) is famous for its sulphur output, not for oil production, and, accordingly, far more is known about the cap rock and the sediments immediately overlying it than about the deeper strata.

HISTORY

Big Hill, after proving an early failure as an oil field, was neglected for a time, and then, within the space of a few years, was developed into one of the world's most important sulphur producers. This was one of a group of topographically prominent domes drilled immediately after the Spindletop boom. William Cash and W. T. Goode were probably the men who first conceived the idea of drilling Big Hill for oil. Sometime during 1901 they acquired about 1,500 acres on and around the hill, and let a drilling contract. Work started at the north end of Block 94, William Simpson League, on the southeast slope of the hill. This first well was drilled in during January, 1902, to about 840 feet, and was a tremendous gasser. All estimates of its production were mere guesses, but the assertion is made that millions of cubic feet of gas per day escaped for a period of several months. This gas was chiefly hydrogen sulphide, an indication of the chief mineral of the dome. Some use was made of the gas, but the major portion of it was wasted.

The Cash and Mayes Syndicate, as the partnership was called, drilled two more wells on the hill to the north of the discovery well, but without success. A short time later T. W. Lane and John Sutherland, of Bay City, formed the Lane-Sutherland Syndicate and drilled a well near the center of Block 78, William Simpson League, north of the Cash and Mayes wells and on the east slope of the hill. A little oil and, what has since proved to be more important, a great thickness of sulphur-bearing limestone, beginning at 900 feet, were found. The well was abandoned in salt water at 1,200 feet.

Mr. Lane sold out to Dr. P. S. Griffith, who made a new location on top of the hill in Block 70, William Simpson League. In May, 1904, this well blew out at 850 feet after penetrating the cap rock a very short distance. The well began flowing at an estimated rate of 2,500 barrels of oil and 3,000 to 4,000 barrels of water per day. The Griffith well served to stimulate immediate activity, and oil production increased until, in December of that year, the average daily output was said to be 4,000 barrels. Salt water then appeared in almost every well, and, by late in December, in such quantity as to decrease the oil production to 1,200 barrels per day. By February, 1905, the production had fallen off to 400 barrels per day.

The boom in the Humble field early in 1905 caused the almost complete desertion of Big Hill. John Sutherland alone remained, pumping several wells by means of windmills and making from 150 to 200 barrels of oil per day. The big storm in the autumn of that year blew down all the derricks, and oil production practically ceased.

Sulphur was found in many places in the drilling of the numerous wells on the hill. These discoveries were merely incidental to the search for oil, but the existence of sulphur was remembered, and this knowledge gave fresh impetus to exploratory work four years later.

In 1909, A. C. Einstein and John W. Harrison, who without very much success were prospecting for sulphur south of Liberty, Texas, decided to drill Big Hill. Their driller, Dr. A. L. Lyons, now of Vinton, Louisiana, took the contract. The first real test for sulphur was made on the northeast slope of the hill, on land of the Matagorda Oil Company, which had acquired the Sutherland, Griffith, and other interests. The results of this well were sufficiently encouraging to cause the formation of the Gulf Sulphur Company, capitalized at $250,000, and the drilling of a series of test wells. All of these wells showed large amounts of sulphur.

Bernard M. Baruch and Seeley W. Mudd became interested in the sulphur possibilities of Big Hill during the year 1910 or 1911. This was not their first venture in sulphur, as they had previously investigated Bryan Heights before it was taken over by the Swenson interests. A thorough drilling and sampling of the sulphur-bearing cap rock of the dome was begun in September, 1916, by Spencer C. Browne, who had sampled Freeport for Baruch and Mudd. The work resulted in the development of one of the largest and most accessible sulphur deposits in the world.

On July 16, 1918, the Texas Gulf Sulphur Company was chartered, succeeding the Gulf Sulphur Company. The capital stock was initially 500,000 shares of $10 par value, but was later increased to 635,000 shares. At first the company could not undertake mining operations and the extensive construction that such work would necessitate because of the scarcity of materials; but the increasing demand for sulphur, due to the prolongation of the world-war, made advisable an immediate start in building. Priority rights were obtained from the government for supplies, and in the face of an extreme shortage of structural materials and machinery the construction of the plant was started in July, 1918, and completed in March, 1919.

The first sulphur was brought to the surface on March 19, 1919, and production has been carried on continuously since then with great success. The Texas Gulf Sulphur Company has become one of the three greatest sulphur producers in the world.

PHYSIOGRAPHY

Big Hill stands one mile from Matagorda Bay in an almost treeless plain that stretches from the wooded "bottom" of Colorado River, 5 miles west of the hill, to Caney Creek, about 14 miles to the east. The land along the bay shore south of the hill rises rather abruptly several feet, then slopes gradually upward, gaining an elevation of 50 feet in about 20 miles. The streams, such as Big Boggy, Peyton, and Caney creeks, have cut down almost to sea-level and formed steep banks in the upper parts of their courses. These are the only topographic features other than the dome itself. There is nothing unusual about the drainage of this area. Some of the water flowing from Big Hill reaches Little Boggy, the nearest stream, $1\frac{1}{3}$ miles to the west. The major portion of the drainage, however, flows directly into the bay.

The mound at Big Hill is roughly oval in shape, elongated in a north and south direction, and measured on the 20-foot contour above sea-level is 4,000 feet long by 2,400 feet wide. It rose to an elevation of 37 feet at its summit before sulphur-mining began. The 22-foot contour line (Fig. 1) shows the true outline of the mound.

In the immediately surrounding country are numerous small ponds and so-called "gas mounds," the latter, in the writer's opinion, being erosion features. Some of these ponds are shown on the northwest part of the contour map.

SURFACE GEOLOGY

The surface material of the mound consists of a yellow clay belonging to the Beaumont. It contains numerous small, dark-colored nodules with considerable iron and manganese. There are also some sandy spots on the surface. The same yellow clay with the same nodules can be found in other places, such as Peyton Creek, 10 miles to the north. At the north end of the hill, on a prominent point that shows quite clearly on the topographic map, the surface is covered by a red clay containing calcareous nodules, probably a variation of the Beaumont. Beyond the dome area the greater part of the surface is "black land," except along the bay front where a natural shell reef has been formed.

SUBSURFACE GEOLOGY

Big Hill is a typical example of a Gulf Coastal salt dome, and has the surface mound and the unconsolidated sediments overlying a salt plug that is capped with a layer of calcium minerals and that has been thrust up through the deeper surrounding strata. In the early days when cap-rock oil was sought, there was little incentive to drill through the cap to the salt plug, and since sulphur-mining has started, such a practice would be disastrous. Therefore little is known about the true shape of this salt core or plug. Such data as are available indicate that the highest part of the plug is about 1,300 feet below sea-level, and that the top of the plug is almost flat, sloping only very gently toward the edges, then suddenly dropping away at a steep angle. As the core is not definitely outlined by drill holes,

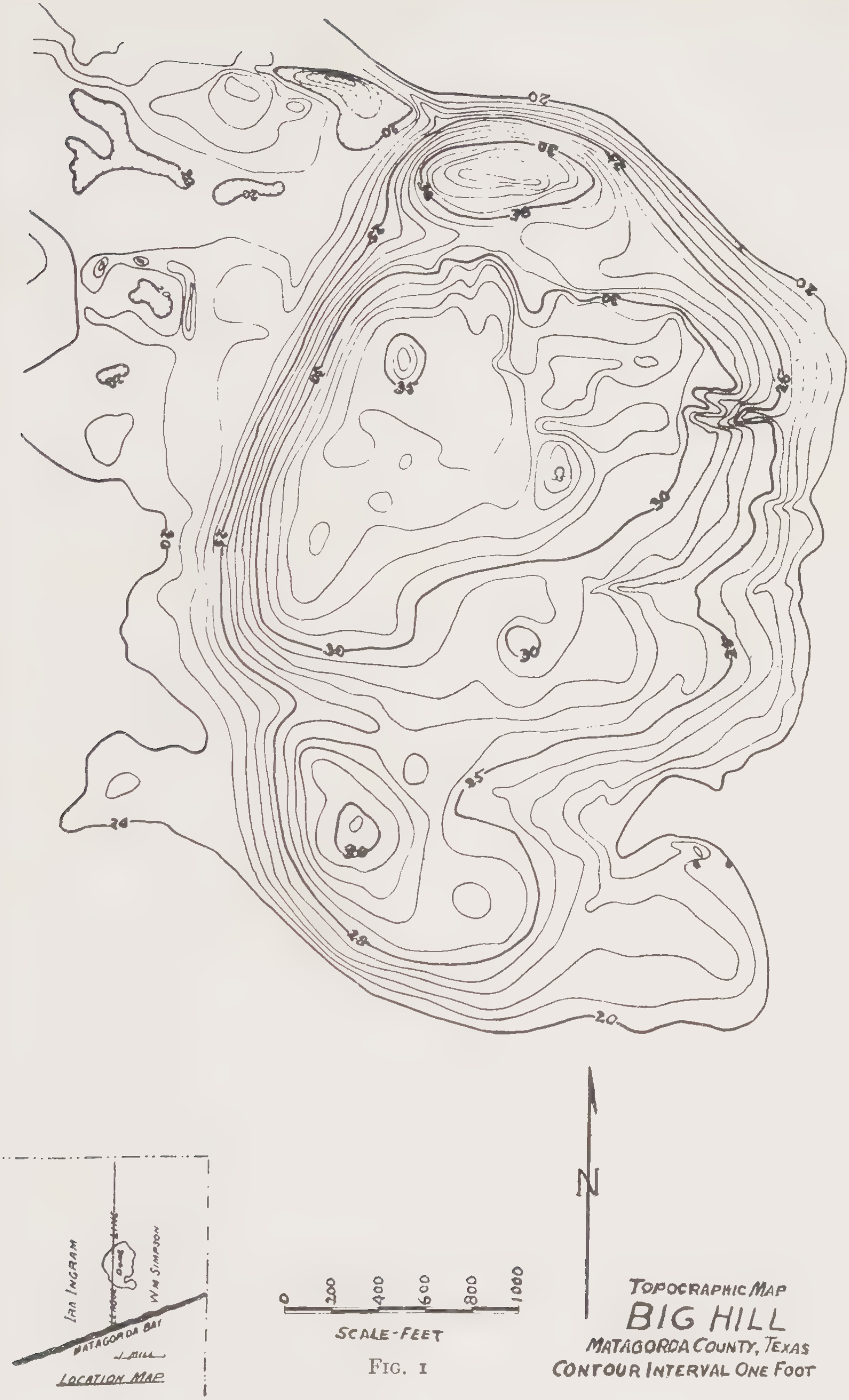
20
30
35
25
24
28
Ira Ingram
Wm Simpson
Dome
Matagorda Bay
Location Map
0
200
400
600
800
1000
Scale-Feet
N
Topographic Map
BIG HILL
Matagorda County, Texas
Contour Interval One Foot

FIG. 1

its size cannot be stated with any degree of accuracy. It is probably elliptical in shape, with an east-west axis of about 4,000 feet, and a north-south axis somewhat longer. The top of the salt, so far as known, and the top of the cap correspond fairly well with the surface topography.

The cap rock is the all-important part of Big Hill. It extends over the entire flattened top of the salt core and down over the flanks of the core a short distance. It underlies more than 300 acres. As its highest point at the center is just 800 feet below sea-level and the salt 1,300 feet, the thickness of the cap is approximately 500 feet at the center. From the center, it thins slightly toward the edges, and pinches out suddenly where it laps over the flanks of the core. Its top is shaped somewhat like the top of the plug, except that its slope is steeper. At the edges of the cap, the slope is abrupt. The steepest slope is on the north.

The cap rock is divided into three parts. On top is a thin layer or zone of porous limestone, barren of sulphur and containing much calcite, and, in the parlance of the sulphur-miner, called the "cap rock." Underlying this is a zone of varying thickness, consisting of limestone identical with that of the cap rock, except that it contains a varying percentage of native sulphur. Beneath the sulphur-bearing horizon, but not so clearly divided from it as the cap rock, there is a very large deposit of anhydrite. The sulphur zone merges into the anhydrite, some residual anhydrite being found in the limestone and sulphur zone, the percentage of calcium sulphate increasing with greater depth while calcium carbonate and sulphur decrease, until anhydrite with only minute crystals of sulphur and microscopic particles of lime is found. Because of this gradual transition, the bottom of the sulphur-bearing zone cannot be sharply defined, and the thickness of the sulphur body depends more on the amount than on the mere presence or absence of sulphur. In some parts of the sulphur pay zone there is a thin lense of barren anhydrite with more sulphur-bearing limestone below it, and the ore fades out into the main body of barren anhydrite at greater depth. Such an occurrence is rare, but interesting, for it appears to be a residual portion of the unaltered calcium sulphate in the secondary limestone and sulphur, and is repeated many times on a very much smaller scale throughout the sulphur zone.

The main features of the dome are illustrated in the accompanying section (Fig. 2). The position of the top of the cap is established fairly definitely, and is so indicated. The limestone-and-sulphur horizon is shown merging into the anhydrite below. The limestone is hatched to the left, the anhydrite to the right, and the intermediate zone, which in some cases is sulphur ore and in others practically barren anhydrite, is shown by the cross-hatched area. No attempt has been made to show the barren limestone layer above the sulphur zone, the cap rock of the sulphur mine, because, in general, it is too thin to show on the drawing. Below the anhydrite is the great rock-salt core.

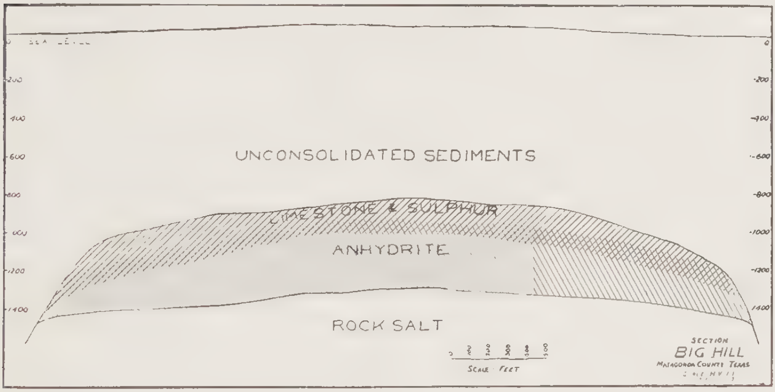

FIG. 2

A partial analysis of a sample from the sulphur-bearing zone is shown in Table I. The probable combination is approximated after correcting the analysis for the iron oxide introduced by pipe scale.

MINERALS IN THE CAP ROCK

Mineralogically the cap is extremely interesting, as economically it is of great importance, and it is far more complex in composition than first appears on cursory inspection.

Sulphur.—The sulphur occurs in massive form in layers and as the filling of irregularly shaped cavities which sometimes are several feet in diameter; in little bunches, specks, and veinlets; and in beautiful orthorhombic crystals, lining vugs. The crystals sometimes occur in the simple pyramidal form, but usually that is modified by a basal pinacoid and by a second pyramid or a brachydome. The color of the sulphur ranges from a bright canary-yellow in both the crystalline and massive forms to dark-brownish and greenish tints in the massive form. It is all extremely pure, and color is no indication of any appreciable percentage of foreign matter.

Calcite.—Well-crystallized calcite constitutes a considerable percentage of the sulphur-bearing zone and of the barren cap rock. It occurs as veinlets between bunches of sulphur, veinlets running in all directions through the limestone, and as the lining of vugs. It crystallizes both as rhombohedrons and scalenohedrons, and in color varies from colorless and white to amber. Some of the calcite has been recrystallized. As limestone, it makes up the main body of the sulphur zone exclusive of the sulphur. The color of the limestone is usually gray. In some places the limestone, calcite, and sulphur are in minute, parallel bands, interspersed with vugs lined by calcite and sulphur crystals. In other places there is a distinct brecciated structure with sharp, angular fragments of limestone cemented together by calcite and sulphur. Figure 3 illustrates this clearly.

TABLE I

ANALYSIS OF SAMPLE OF BIG HILL CAP ROCK FROM SULPHUR-BEARING ZONE

Analysis	Per Cent	Probable Combination	Per Cent
Silica and insoluble	1.2	Silica and insoluble	1.4
Iron and aluminum oxides	15.0	Calcium carbonate	48.1
Calcium	18.9	Magnesium carbonate	2.63
Magnesium	0.65	Calcium sulphate	9.47
CO_3	26.6		

Anhydrite.—Anhydrous calcium sulphate constitutes about 95 per cent of the rock mass between the sulphur zone and the rock salt. It also occurs throughout the sulphur-bearing horizon in a small amount, and can be recognized under the microscope. According to Tomlinson,[1] its texture is crystalline; structure, bedded; origin, precipitate; and metamorphosis, dehydration and deoxidation. It consists of a mass of minute particles with pseudocubic cleavage, the whole having a sugary texture. Dr. J. A. Udden states that specimens showed an irregularly banded structure; that the bands of light-gray and gray anhydrite undulated and ranged in width from mere streaks to 15 millimeters in thickness; and that the light-gray mineral was more finely crystalline than the darker-colored. The chief impurities in the anhydrite are minute crystals of pyrite, small crystals and bunches of crystals of sulphur, and microscopic crystals of calcite.

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[1] Harold W. Tomlinson, Swarthmore, Pa., special investigation.

Strontium minerals.—Both celestite and strontianite occur in the sulphur zone and its cap rock. One piece of sulphur ore contained 35 per cent celestite in small, perfect crystals; and another, 10 per cent strontianite in small veinlets cutting through the calcite. As it is difficult to distinguish microscopically between calcite and strontianite in the same specimen, the estimate of 10 per cent strontianite may not be very accurate (Tomlinson). Granular pyrite occurs in some of the celestite crystals.

Magnesium minerals.—Some magnesium is present in the sulphur horizon, as much as 2.5 per cent in some specimens, but no magnesium minerals have been recognized. Analyses indicate a probable combination in the form of magnesite or dolomite. The percentage of magnesium in no case is sufficient to justify applying the name "dolomite" to any part of the cap rock.

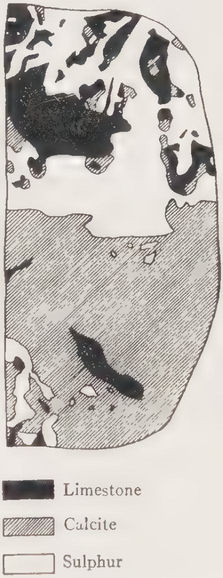

FIG. 3.—Cross-section of core.

Barite.—One specimen from the sulphur zone contained 30 per cent of barium sulphate.

Sulphide minerals.—Pyrite, galena, and sphalerite have been found in the Big Hill cap rock. Pyrite is present through the cap rock from the top of the deepest anhydrite sampled. It occurs in the upper part of the cap in minute crystals, veinlets, and masses. Individual crystals in a few cases are large enough to be recognized by the unaided eye.

Galena is present in small crystalline bunches, associated with pyrite, in the limestone. One selected specimen assayed 0.53 per cent lead, equivalent to 0.6 per cent galena. Well-formed cubes of galena up to 2 millimeters were found also in some sandstone at a depth of 1,600 feet on the outer edge of the dome.

Only one small particle of sphalerite, so far as known, has been observed. No assays have been made for zinc in specimens of cap rock.

Quartz.—Fractional percentages of silica occur in the limestone and anhydrite. Limestone from the sulphur horizon digested in acid left perfect, double-pyramidal quartz crystals $\frac{1}{8}$ – $\frac{1}{32}$ millimeter in length (Udden).

UNCONSOLIDATED SEDIMENTS

The sediments above the cap rock can be classified as clays, sands, and marls. Dr. Udden made an exhaustive study of the logs of sixty-two wells drilled within the area of the Big Hill rock and the aggregate 60,000 feet of drilling represented by these reports were classified, according to the drillers' terminology, as follows:

TABLE II

Aggregate Thickness of Rock Types Reported in Sixty-two Big Hill Well Records

Formation	Total Feet Drilled	Per Cent of Total Drilled
Gumbo	30,701	49.6
Shale	8,865	14.3
Clay	6,244	10.1
Sand	11,394	18.4
Gravel	874	1.4
Shell	656	1.1
Rock	3,148	5.1
Total	61,882	....

These are the main divisions, including such subdivisions under each heading as "gumbo and bowlders," "clay and sand," "shale, shell, and sand." This summary is of interest because it shows the relative amounts of the various materials found in the supercap zone.

Rock, as classified above, ranges from slightly hardened concretions through all gradations of sandy limestone and sand cemented by lime. The total footage of rock shown does not lie in a few well-defined strata overlying the entire cap-rock area, but in a great number of lenses, small in extent, and usually quite thin. Rarely does a rock stratum found in one well extend laterally 100 feet in any direction. In the sixty-two wells, 406 beds of rock were reported. Their thickness and distribution are shown in Tables III and IV prepared by Dr. Udden.

This shows that more than one-half the total amount of rock reported in these sixty-two wells is within 50 feet immediately above the cap rock. Any rock reported over 550 feet above the cap is insignificant in amount. These conditions are probably representative of the entire area of the dome. The distribution of thickness of individual beds is given in Table IV.

TABLE III

DISTRIBUTION AND THICKNESS OF ROCK IN SIXTY-TWO BIG HILL WELLS

Distance above Sulphur in Feet	Per Cent of Rock in Each 50 Feet	Total Footage of Rock in Each Division
550–500	0.3	10
500–450	0.2	9
450–400	0.3	12
400–350	0.9	28
350–300	2.7	86
300–250	4.0	133
250–200	9.1	283
200–150	18.3	569
150–100	12.8	399
100– 50	11.7	369
50– 0	53.7	1,665

Of the numerous strata found in the hundred or more wells drilled on the dome, only three appear to be at all continuous. These are the surface clay, the shallow sand just under the surface clay, and the thick gumbo stratum immediately overlying the dome cap rock. The intermediate strata are flat lying and extend only short distances, apparently not over 100 feet laterally. Apparently they are lense shaped, overlapping one another like shingles on a roof. Part of this seeming irregularity, no doubt, is due to the difficulty in logging correctly a number of thin strata drilled rapidly by the rotary method and by different drillers; but there can be little question of the existence of great irregularity in the bedding of these recent deposits.

Considerable paleontological work has been done on the supercap sediments, but though it is certain that the uppermost beds are Pleistocene, no definite opinions have been obtained regarding the probable dividing lines between the deposits of various ages. That some of the sediments overlying the dome are Pliocene, and possibly even older, is almost certain, for Pliocene beds are known to be relatively high in this part of the Gulf Coastal plain. The problem of distinguishing between the Pleistocene and Pliocene deposits in Texas is difficult,[1] so it is not surprising that it has not been definitely solved at Gulf. The following tabulation shows some of the fossils found above the cap rock at Big Hill and the depths at which they were found. The determinations were made by the Bureau of Economic Geology and Technology, University of Texas, Austin:

TABLE IV

DISTRIBUTION OF THICKNESS OF ROCK STRATA AT BIG HILL

Thickness of Individual Beds in Feet	Per Cent of Total Number of Beds Reported (406)	Per Cent of Total Footage Reported (3,563)
1– 5	56.0	21.2
6–10	23.8	23.6
11–15	7.6	12.3
16–20	4.1	9.5
21–25	2.4	6.1
26–30	2.7	9.6
31–85	0.85	19.2

FOSSILS FROM THE SUPERCAP SEDIMENTS AT BIG HILL

Depth Below Sea Level in Feet	Fossils Identified
100–150	Ostracods, *Chara* fruit case, *Rotalia*-like Foraminifera less than ½ millimeter in size
150–180	*Rotalia*-like Foraminifera, one *Anomalina*
180–200	Fragments of barnacles, small pelecypod, smooth ostracod, gastropod, and *Rotalia* sp. and *Polystomella* cf. *craticulata* (Pliocene?)

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[1] J. A. Udden, C. L. Baker, and Emil Böse, "Review of the Geology of Texas," *Bulletin 44* (1916), p. 121.

Depth Below Sea Level in Feet	Fossils Identified
200–250	Shreds of lignitic material, pelecypods, minute *Polystomella*
250–350	Thin mollusk-shell fragments, limonitic shreds of vegetal matter
At 350	*Ostrea* conglomerate consisting of shells imbedded in a marly matrix in part slightly indurated. Also *Rotalia* sp. and *Polystomella* sp., molds of large portions of *Mytilus* shells. (Might be Pliocene?)
350–500	Oyster-shell fragments, soft lignite
540–550	Pelecypods, gastropods, fish scales, teeth, Foraminifera including *Rotalia*, *Polystomella*, and *Anomalina*
640–680	Barnacle-shell fragments, oyster shells, pelecypod shells, ostracod valves, Foraminifera resembling *Rotalia*, *Polystomella* (sp?)
770–780	Barnacle fragments
812–	Fragments of oyster shells

Little deep drilling has been done at Big Hill, and the structure of the surrounding beds, has not been established precisely. There is little doubt, however, that the lower beds dip in all directions away from the core at a high angle near the dome. Insufficient information has been collected to warrant any statements regarding the stratigraphy of the deeper beds. These lateral sediments consist largely of gumbo and shale, to use the drillers' terminology, with some marl and sandy marl. "Black shale," similar to that at West Columbia, Damon Mound, and elsewhere, has been found here at depth. According to Joseph A. Cushman, gumbo samples from about 1,600 feet in one well on the edge of the dome contained Foraminifera strongly suggesting either Lower Oligocene or Upper Eocene, with the probabilities in favor of the latter. This would indicate a considerable uplift, perhaps 3,000 feet.

AGE OF THE DOME

Nothing can be stated with any degree of assurance regarding the geological history of this dome, although it is likely that all coastal domes are of approximately the same age. If we accept the intrusive origin of the domes as correct, the major movement at Big Hill probably occurred during the Pliocene. It is doubtful if any amount of exploratory work and scientific investigation would lead to a closer estimate. If the cap rock is of secondary origin as compared with the salt core, and the writer believes that it is, part of the deformation of the later or Pleistocene beds may have been caused by its accumulation. The age of the cap rock is equally as indeterminate as that of the core, and its relative age is dependent on the mode of formation ascribed to it. If of secondary origin, it is of course younger than the salt core. If the caps of the various domes were first deposited as anhydrite and later hydrated to gypsum,[1] where that mineral occurs, then the cap rock at Big Hill may be relatively young as compared with that at Damon Mound, for example, for no such hydration has taken place at Big Hill. If the anhydrite was formed by the dehydration of gypsum, then the cap there apparently is old as compared with many of the dome caps.

ORIGIN OF THE DOME

The possible origin of Gulf Coastal salt domes is a subject that has been discussed at too great length to be given a comprehensive review here. It is generally recognized that the subject must be approached from three standpoints: the cause of the uplift, the source of the salt, and the origin of the cap rock. The uplift has been attributed to the deposition of either the salt or of the cap rock, or, in part at least, to chemical changes in the cap rock after deposition. Little can be added to this discussion by any discovery made at Big Hill to date, except to state that the structure of the dome as a whole tends to strengthen the theory of salt intrusion.[2] A handy reference for those who wish to make a detailed study of this problem is a complete tabulation of the theories advanced to date in the writer's "The Origin of Salt Domes."[3]

The formation of the cap rock is undoubtedly secondary to the salt intrusion. Examined under the microscope, the cap-rock material proves to be a precipitate. But the presence of a warm, saturated brine makes it almost impossible to explain the deposition of gypsum from solution; and the compactness of the anhydrite suggests the improbability of the formation of this great, massive sheet by dehydration of gypsum. Anhydrite on the other hand is formed by precipitation from sea water at 86° F., or possibly over. The brecciated structure of the upper part of the cap rock, as described under "Calcite," seems to indicate that the upthrust did not occur all at one time, but in successive movements that broke up the higher portion of the cap. Uplift followed by cementation by calcite and other minerals precipitated from circulating solutions would have produced the structure noted.

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[1] Donald C. Barton, "The West Columbia Oil Field," *Bull. A.A.P.G.*, Vol. 5, No. 2, (March, 1921), pp. 220 and 225.

[2] G. S. Rogers, "Intrusive Origin of the Gulf Coastal Salt Domes," *Econ. Geol.*, Vol. 13 (1918), No. 6, pp. 447–86.

[3] "The Origin of Salt Domes, a Chronological Tabulation of Theories Thus Far Advanced," *Eng. and Min. Jour.-Press*, Vol. 115 No. 9, (March 3, 1923), p. 412.

The original brine in the cap rock must have been very strong. A sample of the water coming from the mine in April, 1921, after fresh water had been pumped into the dome for two years, gave the following analysis:

TABLE V

	Grains per Gallon		Per Cent
Silica	1.2	Alkalis	40.65
Calcium sulphate	197.0	Earths	9.35
Iron and aluminum oxides	0.6	Strong acids	48.67
Calcium bicarbonate	19.0	Weak acids	1.33
Calcium chloride	431.0	Primary salinity	81.3
Magnesium chloride	189.0	Secondary salinity	16.0
Sodium chloride	3,670.0	Secondary alkalinity	2.7
Specific gravity	1.052		

OIL AND GAS

The first well drilled into cap rock at Big Hill blew in a big "gasser." Most of this gas was hydrogen sulphide, but no analyses were made to determine what proportion was "sulphur gas" and how much petroleum gas. Subsequent wells produced considerable oil, all of it from the uppermost, cavernous part of the cap rock. This oil had a greenish tint, and was of the usual coastal gravity, about 20° Baumé.

The major production of oil was made before the end of 1905, and probably did not altogether exceed 500,000 barrels. During the years 1904 to 1907 inclusive, Matagorda County produced 203,580 barrels.[1] It is certain, therefore, that the estimate of one-half million barrels is liberal. After the Texas Gulf Sulphur Company started operations in 1919, a few old wells and one new prospect well in the cap rock flowed a small amount of oil, and created a mild excitement among the uninitiated. This flow was nothing more than the "dying gasp" of the dome as a producer of cap-rock oil. The great quantity of hot water forced into the sealed structure of the dome lifted the remaining portion of the oil to the top and out through these open holes. All these wells soon went to water.

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[1] *The Manual for the Oil and Gas Industry* (revised to 1921, Treasury Dept. U. S. Int. Rev.), p. 218.

An idea still persists that improper handling of one or more of the cap-rock wells in the early days allowed a sudden incursion of salt water, which materially reduced the possible production of the field. The writer is quite certain that this theory is wrong. The salt water of the dome simply followed the oil as it was being withdrawn from this reservoir, and made its appearance in the walls when the lighter fluid was exhausted. Today there probably does not exist in the entire cap rock sufficient oil to fire a "pot" for one more shallow test.

Early failure of Big Hill to prove a second Spindletop, and the subsequent development of the great sulphur deposit, have both served to retard deep oil-well drilling and to distract attention from the possibilities of producing deep oil. Perhaps twenty wells, all told, have been drilled outside the cap-rock area to depths reported as ranging from 1,000 to over 3,000 feet. These wells were scattered over a large area, and the fact that no great oil discovery has been reported does not militate against the possibility of such a discovery in the future. Some of these wells were drilled during the early development of the oil field, and it is probable that the reported results are inaccurate, and also that the full possibilities of the areas tested are not exhausted.

The only oil production from lateral sands was made from two wells on the southeast slope of the dome in the Gulf townsite. These wells produced a few hundred barrels of the average coastal gravity, and then went to salt water. This production has been grossly overestimated by rumor. The oil may have come from a small pool that was trapped there by a late domal movement while seeping along some fault crack from a deep-seated source, possibly a black shale, toward the main reservoir in the cap rock.

SULPHUR

Many salt domes have produced oil, but to date only four have produced sulphur. Because of the tremendous importance of sulphur to civilized man, the great deposit at Big Hill—or Gulf, as we must now call it—is of far greater moment than any amount of petroleum that ever could be produced there.

Origin of sulphur.—Sulphur deposits in general are formed by either volcanic or hot-spring activities, or are found in close association with limestone, gypsum, and anhydrite in sedimentary beds. The world's greatest sulphur bodies, those of Sicily and the Gulf Coastal region of Texas and Louisiana, belong to the latter class. As these two groups are similar in many respects, as the Sicilian deposits have been the subject of intensive study for many years, and as relatively little is known about the coastal dome formations, we are forced, in any discussion of the subject of the origin of these beds, to consider the theories advanced for the formation of the Sicilian sulphur bodies as applying to those of our salt domes. The European mines are operated by means of open cuts and underground workings which afford ample opportunity for study, but we must content ourselves, in the case of salt domes, with the meager samples brought up by the core barrel.

The following paragraph from the description of the Sicilian deposits by O. Stutzer[1] might have been written about the sulphur ore at Gulf:

> The parallel sulphur bands of these occurrences consist chiefly of compact sulphur. Occasionally they exhibit on their upper surface hollow spaces into which calcite crystals project. Sulphur crystals have also formed on this compact sulphur along these cavities. The hollow spaces, bordered below by sulphur and above by a layer of calcite, together with their accompanying crystals, have originated through secondary solution and redeposition. The beautiful sulphur, gypsum, and celestite crystals which the Sicilian mines have contributed to the mineralogical collections of the entire world are likewise secondary products, which have formed later along fissures.

It is now almost universally accepted that the sulphur was the result of the oxidation of hydrogen sulphide according to the reaction: $H_2S+O=H_2O+S$. Also, that the hydrogen sulphide was derived from the decomposition of organic material, or from the reduction of inorganic sulphates by means of organic substances. In the case of the salt domes, as with the Sicilian deposits, the great masses of gypsum or anhydrite present make it appear most probable that the sulphates of calcium supplied the sulphur.

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[1] "The Origin of Sulphur Deposits," from an article on sulphur in *Die Wichtigsten Lagerstätten der Nicht-Erze* from translation by W. C. Phalen. Berlin: Borntraeger Bros., 1911.

In discussion of the derivation of hydrogen sulphide from calcium sulphate—a complex question—several methods of derivation must be reviewed. Bischof[1] proposed the following reactions:

$$CaSO_4+2C=CaS+2CO_2$$
$$CaS+CO_2+H_2O=CaCO_3+H_2S$$
$$H_2S+O=H_2O+S$$

To quote Lindgren:[2]

> The objection to this scheme would be that the sulphur is evidently often formed at depths of several thousand feet, and that the presence of much oxygen at such depths would be impossible; more likely the hydrogen sulphide generated from the gypsum reacts upon calcium carbonate, resulting in secondary gypsum and sulphur.

As some of the domes, at least, are open to the circulation of unlimited quantities of artesian water which might carry oxygen and carbon dioxide in solution, the foregoing objection is overcome. The immense excess of calcium sulphate over all other minerals of the cap rock combined appears to make the secondary reaction suggested by Lindgren impossible.

Riesenfeld[3] states that the reaction between gypsum and carbon below 500° C. proceeds very slowly, but is fairly rapid above 700° C., the reaction taking place according to the equation:

$$CaSO_4+3C=CaS+CO_2+2CO.$$

Similar results were obtained with the sulphates of strontium and barium, while the indifferent behavior of magnesium sulphate is explained by the heats of reaction. He also claims that CaS cannot be decomposed according to the equation (equilibrium):

$$CaS+H_2O+CO_2 \text{ to } CaCO_3+H_2S,$$

since CaS is formed to a considerable extent at temperatures such as 700° C., at which the equilibrium is sufficiently rapidly attained.

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[1] G. Bischof, *Chemie und Physikalische Geologie*, Vol. 2 (1851), pp. 144–64.

[2] Waldemar Lindgren, *Mineral Deposits* (1919), p. 384.

[3] E. H. Riesenfeld, *Jour. Prakt. Chem.*, Vol. 100 (1921), pp. 115–58.

The reduction of gypsum by methane in experiments took place according to the equation:

$$CaSO_4+CH_4=CaS+CO_2+2H_2O.$$

Dehydration of gypsum occurred below 800° C. Some calcium oxide was formed above 1,100° C., probably according to the equation:

$$CaS+H_2O=CaO+H_2S.$$

An excess of steam favored the complete removal of sulphur at 1,200°–1,300° C.; the sulphur was obtained as sulphur dioxide or free sulphur; the latter predominated in a slight excess of water, due partly to dissociation of hydrogen sulphide and partly to its reaction with water vapor.

The carbon involved in the reduction of the sulphate might be derived from petroleum. Another process of reduction was advanced by Hoppe-Seyler[1] whereby methane is the reducing agent according to the probable reaction:

$$CH_4+CaSO_4=CaCO_3+H_2S+H_2O.$$

Kreummer and Ewald[2] stated that the walls of a cavity in gypsum in the Baringhausen mine showed alteration to calcite and impregnation with bitumen to a depth of several centimeters, and were covered by numerous sulphur crystals. Gases in the cavity were hydrocarbons and a trace of hydrogen sulphide. Sulphur was formed evidently by the reactions:

$$\begin{gathered}CaSO_4+CH_4=CaCO_3+H_2S+H_2O\\ H_2S+O=H_2O+S\end{gathered}$$

It is quite easy to conceive that methane in quantity might have existed in the sealed dome at Gulf, where some oil was present. One objection to the carbonaceous reduction theory is the high temperature necessary to the reaction. It is within the bounds of reason, however, to assume that great heat was produced by upward movements of the salt plug.

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[1] *Zeitschrift für Physiol. Chemie*, Bd. 10 (1886), S. 401.

[2] A. W. Kreummer and R. Ewald, *Centr. Min.* (1912), pp. 638–40.

Another method proposed for the derivation of hydrogen sulphide from calcium sulphate is by bacterial reduction. Certain micro-organisms, anaerobic bacteria, reduce sulphates and liberate hydrogen sulphide. The first exhaustive study of sulphate-reducing bacteria was made by Beyerinck.[1] A thorough exposition of this theory is given by Hunt[2] in his paper, "The Origin of the Sulphur Deposits of Sicily." To quote from this work:

> Such a bacterial reduction theory, with its accompanying chemical reactions, would explain the presence of disseminated and banded sulphur in the limestone, the unusual absence of the sulphur-limestone rock in the gypsum above, and the formation of the sulphur at normal temperatures and under conditions which would confine its formation and deposition to these land-locked basins.

This might well apply to the Sicilian deposits which could have been formed in shallow lagoons; but to attribute this mode of sulphur formation to our coastal dome deposits would necessitate a return to one of the apparently untenable theories of the building up of the salt structure concurrently with the surrounding sediments.

According to studies by Baker,[3] the oxidation of hydrogen sulphide where oxygen is in excess, as at the surface, is complete, and sulphuric acid results; but below the surface, where oxygen is deficient, sulphur is liberated.

Another tentative theory that has been advanced may be expressed in the following equations:

$$2CaSO_4 + 4C = 2CaS + 4CO_2,$$

or

$$2CaSO_4 + 8C = 2CaS + 8CO.$$

These reactions could take place outside the dome area. Water might then take the calcium sulphide into solution:

$$2CaS + 2H_2O = Ca(SH)_2 + Ca(OH)_2,$$

the hydrate precipitating and the calcium hydrosulphide remaining in solution until it comes into contact with water charged with carbon dioxide, when it would be precipitated:

$$Ca(SH)_2 + CO_2 + H_2O = CaCO_3 + 2H_2S.$$

[1] W. M. Beyerinck, *Centralbl. f. Bakt., 2d Abt.*, Vol. 1 (1895), pp. 49, 104.

[2] Walter F. Hunt, *Econ. Geol.*, Vol. 10, No. 6, pp. 543–79.

[3] G. F. Baker, *Monograph, U. S. Geol. Surv.*, Vol. 13 (1888), p. 576.

The hydrogen sulphide would then have to be oxidized, with the formation of water and the liberation of sulphur. Considerable chemical research is necessary to prove even the possibility of this theory.

One almost insurmountable argument in favor of the theory that the sulphur was formed in place from the reduction of calcium sulphate, with the resulting formation of calcium carbonate and native sulphur, is the relative proportion between the calcium carbonate and the calcium sulphate and the sulphur, as shown by a series of analyses of the sulphur body at Gulf from various depths. The carbonate increases and the sulphate decreases with an increase in the amount of sulphur present.

Minor structural details of the sulphur body could be explained by the breaking up of the rock due to upward movements of the core, alteration of the calcium sulphate in place, and the deposition of calcium carbonate and sulphur in the interstices. Slight movements tending to fracture the top of the cap might have taken place coincidently with the formation of sulphur. The finely laminated part of this deposit, where the layers of limestone, calcite, and sulphur alternate, might conceivably be due to the banded structure of the anhydrite and the variation of its texture in these bands.

SAMPLING

Although sulphur is extracted from the deposit through wells like those drilled for petroleum, its recovery is essentially a mining process; to carry on successful operations, therefore, it is necessary to know the grade of the ore. Sulphur sampling in general is accomplished by drilling wells to the cap rock, and then recovering the portion of the sulphur-bearing formation drilled through, by one of several different processes, such as completing the hole with water instead of mud as the circulating medium and catching the cuttings; by reversing the flow, with or without the addition of extra water, and collecting the cuttings; or by coring.

At Gulf the well drilled for sampling is first sunk to cap rock by the usual rotary method. A core is taken to make sure of the character of the formation. Casing is set on rock to cut off all material from above, and all mud is washed from the hole.

Because of the porous nature of the deposit, much of the cuttings and drilling water would be lost if the water forced down through the drill stem were relied on for "returns." Coring is also unsatisfactory, because of the friable nature of the minerals. These conditions make it necessary to reverse the flow in the well, drawing the cuttings as fast as they are formed, along with the drilling water, up through the drill stem. This is done by means of an air lift within the drill pipe.

A hole is drilled in the top of the goose-neck of the swivel, and around it a seat is machined for a light swivel which supports the air line. From 250 to 300 feet of ½-inch galvanized pipe, with left-hand threads, is run into the stem, and the air line is connected with any source of compressed air under 120 pounds pressure. The ordinary fish-tail bit is used, but with holes enlarged to 1¼ inches to reduce the possibility of clogging by large cuttings. As a rule, no water is needed; sufficient comes in from the formation. When necessary, it is run into the top of the casing. As drilling proceeds the compressed air released into the ½-inch line forms an air lift inside the drill stem and the cuttings are drawn into the stem through the holes in the bit and forced out through the hose leading from the goose-neck of the swivel. These cuttings are carefully collected on a screen and in a series of settling boxes fitted with baffles in such a manner that even the finest cuttings are forced under the surface of the water and saved.

This method of sampling sulphur-bearing rock was developed by Spencer C. Browne, a mining engineer of New York City, during the early exploration of the sulphur deposit at Bryan Mound, Brazoria County, Texas. The advantages of the method are rapidity, accuracy, and flexibility. Samples from any footage of the formation can be taken, and the cuttings of each sample can be kept separate by allowing sufficient time for the hole to wash clean. Samples are first carefully dried on a water-bath so as not to fuse any of the sulphur, and are then cut down, and assayed. The reject is saved for future reference.

SULPHUR-MINING

Herman Frasch in 1891 invented the process of extraction now used in all Gulf Coastal sulphur mines. It embodies the ideas of melting the sulphur in the ground by means of superheated water, and raising the sulphur in a molten state to the surface of the earth.

Pumps were first used for the latter purpose, but were soon replaced by compressed air.

Economic and large-scale extraction of sulphur by this process can be carried on only where a big sulphur deposit of good grade occurs under favorable geological conditions. In addition to the natural requirements, a boiler plant of large horse-power, together with water heaters, high-pressure pumps, and air compressors are necessary to supply the enormous volume of hot water under pressure, and the compressed air; as well as drilling equipment and a thoroughly trained crew to sink, equip, and operate the sulphur wells.

At Gulf, a well is sunk rapidly to cap rock; a carefully drawn cap-rock contour map aids materially in predicting where it will be struck. Eight-inch casing is set, and the hole is drilled to the bottom of the sulphur-bearing formation. The well is then ready for the equipment, which consists of a 6-inch, a 3-inch, and a 1-inch line, all set concentrically, and connected with each other above the surface by expansion joints.

Two groups of holes are drilled in the 6-inch pipe, near the bottom and a few feet apart. The lower group constitutes the sulphur "strainer," where the molten sulphur flows into the pipe, and it is so placed that it will be at the very bottom of the sulphur pay. The upper group of holes serves as an outlet for the hot water. Between these two groups of holes is a seat that supports the string of 3-inch pipe. The 1-inch pipe is supported from the top, and extends to within approximately 20 feet of the bottom of the 3-inch string.

In "steaming" a well, water heated in the plant to about 325° F. is forced down between the 3-inch and 6-inch pipes under 95–250 pounds' pressure. The sulphur melts and runs to the bottom of the well, as its specific gravity is about twice that of the water. From there, it is forced part way up the 3-inch pipe by the water pressure, and elevated to the surface by compressed air under 500 pounds' pressure, which is released from the bottom of the 1-inch line. Under certain conditions, some wells will pump steadily while "taking water"; others will not. When the molten sulphur ceases to "pump," the water comes up through the 3-inch pipe and flashes into steam. The well is then said to "blow." Air is cut off, and water alone must be pumped into the well for a number of hours until more molten sulphur has collected at the strainer. If the well then pumps sulphur, it is said to have "sealed." While the well is not pumping sulphur, water can be forced in through the 3-inch pipe as well as through the 6-inch and accelerate the melting process.

The liquid sulphur is conducted from the wells to the vats through pipes fitted with an inner steam pipe. The vats are built of lumber and are of light construction, as the sulphur solidifies almost as fast as it is run into them. The vats vary in size, but are now built up to about 50 feet in height. A single vat at Gulf contained at one time about one million tons in a single block. When a vat is filled, the wood forms are torn down. Vertical holes are drilled several feet back from the face by a specially designed, light rotary rig. The holes are sprung with light charges of dynamite, and then shot with heavier charges. Electric firing is employed. The broken sulphur is loaded into gondolas by locomotive cranes, and into box cars by cranes and Ottumwa box-car loaders. The details of handling sulphur after it is won from the earth is beyond the province of this paper.

The mine-water heating plant contains fourteen Sterling water-tube boilers of 702 horse-power each, eight jet-type water heaters, thirty-four duplex slide-valve pressure-pumps, and six Laidlaw-Dunn-Gordon compressors. The boilers supply steam to the water heaters, to the compressors, turbo-generators, and the various pumps. One-half the pressure-pumps force water into the heaters against the steam pressure of the boilers, and the other half, called the "booster pumps," send the water to the wells under pressures up to 250 pounds when necessary. The heaters raise the temperature of the mining water to nearly the temperature of live steam under 95–105 pounds, pressure, approximately 325° to 335° F.

The plant was designed with the expectation that it would produce 1,000 tons of sulphur per day. This anticipation was based on the results of the older sulphur-mining installations. But as a matter of fact, five times this amount has been produced. This phenomenal success is due in part to a careful study of every phase of the mining problem, especially of the principles of thermo-dynamics involved, and the application of every economy and simplification in the process. Too great credit cannot be given the efficient executive and technical control of the operations. A more important reason for the unexpected success in mining operations is the existence of an enormous deposit of sulphur surrounded by almost ideal structural conditions. The deposit lies at a depth from which it is not difficult to elevate the sulphur to the surface. Its entire top is overlaid and effectually sealed on that side by a thick stratum of gumbo; the enormously thick bed of barren anhydrite serves the same purpose below. Any hot water forced into this sulphur-bearing zone is trapped, and must give up a large part of its heat. As the same volume of water introduced must be drawn off, "bleed wells" are drilled around the outer edge of the deposit and draw the waste water from a deeper and cooler zone than that in which the sulphur is being melted.

After sufficient sulphur has been removed from any given area, the porous rock remaining breaks down under the weight of the overlying sediments, and the gumbo flows into the cavity. This movement is manifested by a subsidence of the surface, and is a desirable action, because the volume once occupied by sulphur is filled by rock and gumbo, and the quantity of water required to fill the reservoir is reduced; furthermore, the hot water, restricted in its flow, is forced to circulate where a large part of its heat will be utilized in melting sulphur. The subsidence is slow and uniform, and progresses without shock, on account of a great preponderance of unconsolidated strata between the sulphur pay and the surface. If the barren limestone, the sulphur-miner's cap rock, immediately over the sulphur-impregnated limestone, were thick and capable of supporting great weight, the subsidence might conceivably take place at long intervals and with great violence, or not at all. Due to the relative thinness of the barren, but porous, limestone "cap," not much hot water is wasted in filling this part of the underground reservoir.

IMPORTANCE OF SULPHUR

Although the Gulf Coastal area is an oil-producing region of considerable importance, it does not supply more than about 5 per cent of the average daily output of the United States, and the loss of this quantity would not be a disastrous blow to the commercial activities of the United States. Not so with sulphur, however. The three great coastal sulphur-mining companies of Texas and Louisiana furnish over 99 per cent of this mineral produced in the United States and, in round figures, 75–80 per cent of the world's production. Table VI shows the output of sulphur by the major contributing countries, and the movements of sulphur; and demonstrates quite clearly the domination of the sulphur industry of the world by these Gulf Coastal mines.

TABLE VI

WORLD-PRODUCTION AND CONSUMPTION OF SULPHUR*

	PRODUCTION			EXPORTS AND IMPORTS			
	U.S. Long T.	Italy Met. T.	Japan Met. T.	U.S. Shipments Long T.	U.S. Exports Long T.	U.S. Imports Long T.	Italy Exports Met. T.
1909.....	273,983	402,353	36,317	258,283	....	26,914	364,953
1910.....	247,060	397,808	43,848	250,919	30,742	28,647	395,944
1911.....	205,066	376,161	52,064	253,795	28,103	24,250	456,227
1912.....	787,735	356,555	55,005	305,390	57,736	26,885	447,590
1913.....	491,080	345,548	59,481	319,333	89,221	14,636	414,716
1914.....	417,690	334,974	75,308	341,985	98,163	22,810	338,308
1915.....	520,582	319,260	73,369	293,803	37,271	24,647	359,806
1916.....	649,683	233,835	108,100	766,835	128,755	21,510	396,035
1917.....	1,134,412	177,453	117,990	1,120,378	152,736	973	162,971
1918.....	1,353,525	194,585	64,696	1,266,709	131,092	55	230,769
1919.....	1,190,575	181,744	67,382	678,257	224,712	77	147,286
1920.....	1,255,249	224,247	21,147	1,517,625	477,450	44	189,878
1921.....	1,879,150	240,089	33,106	954,434	285,762	4	105,542
1922.....	1,830,942	137,640	....	1,343,624	485,664	7,960	137,352

**Mineral Industry*, Vol. 31. New York: McGraw-Hill Book Co., 1922.

A broad division of the industries using sulphur as a direct constituent of their finished products or as a reagent in their manufacture may be made as follows:

1. Acids and chemicals
2. Acid phosphate
3. Paper
4. Agriculture (other than acid phosphate)
5. Rubber
6. Galvanizing
7. Explosives

Sulphur is of considerable importance to the petroleum industry in the form of sulphuric acid used in the process of refining. An enumeration of all the articles indispensable to the petroleum industry that require sulphur in their process of manufacture is out of the question here, to say nothing of the innumerable things used every day by the average man; but one may be so bold as to say that the world today could as easily get along without petroleum as without sulphur. On the other hand, petroleum solved the problem of cheaper fuel for the sulphur industry, and made it possible for the Frasch process to succeed; so the two great industries are mutually indebted to one another.

Since 1919, Gulf has played a tremendous part in adding to the giant sulphur output of the United States, and ranks foremost today in potential production. With its reserves of many millions of tons, Big Hill, Matagorda County, Texas, will continue for years to be one of the dominating factors in the sulphur industry of the world.

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THE SALT DOMES OF SOUTH TEXAS[1]

DONALD C. BARTON[2]

ABSTRACT

In south Texas, there are three known salt domes, Palangana, Piedras Pintas, and Falfurrias; three possible domes, Sal del Rey, Sal Vieja, and Chapeño; and two much less probable domes, Smith Corkill and La Lomita. The structure of Palangana, fairly well known from drilling, is that characteristic of an American salt dome, and is distinctly reflected in the topography. Palangana has no production. At Piedras Pintas, the salt and cap have been drilled into, but not much is known in regard to the structure of the dome. Piedras Pintas has a small, shallow oil field. Both domes gives evidence of the very great upthrust of the salt. On the basis of the evidence afforded by the German salt domes, the origin of salt domes is the plastic deformation of sedimentary salt beds. The origin of salt domes is the plastic deformation of sedimentary salt beds. The origin of the cap, such as is present at both Palangana and Piedras Pintas, has not been satisfactorily explained, although several plausible theories have been proposed. At Falfurrias, the salt has not been encountered, but the presence of a characteristic salt-dome mound and characteristic cap rock indicate the presence of a salt dome. Sal del Rey and Sal Vieja are saline lakes whose topography in a general way is similar to that of a central-depression type of salt-dome mound. The lakes, however, are more probably due to wind activity with concentration of normal surface waters in the wind-scooped basins. Chapeño suggests salt-dome structure in the presence of sulphur deposits. La Lomita is a mound near the Rio Grande, and Smith Corkill is a group of chalcedonic knobs.

INTRODUCTION

In south Texas there are three known salt domes, Palangana, Piedras Pintas, and Falfurrias; and several possible domes, Sal del Rey, Sal Vieja, Chapeño (over the border in Mexico), and less probably Smith Corkill and La Lomita, which have some of the surface aspects of domes, but which are not proven domes (Fig. 1). Piedras Pintas and Falfurrias have long been known, but have not been well described.

SOURCES OF INFORMATION

Information concerning the south Texas domes and possible domes was obtained by personal work in the field by the author in the case of Palangana, Piedras Pintas, Falfurrias, Sal del Rey, Sal Vieja, detailed work by his assistant, O. H. Eichelberger, around Sal del Rey and Sal Vieja; descriptions by various geologists in the case of Chapeño; Mr. Deussen's report and descriptions by several geologists in the case of Smith Corkill; and Mr. Trowbridge's paper and descriptions by several geologists in the case of La Lomita. The author is indebted to the geological departments and geologists of the Sinclair Oil and Gas Company, the National Oil Company, the Empire Gas and Fuel Company, the Humble Oil and Refining Company, for well logs at Palangana and Piedras Pintas; and to Miss

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[1] Published by permission of the Rycade Oil Corporation, Houston, Texas.

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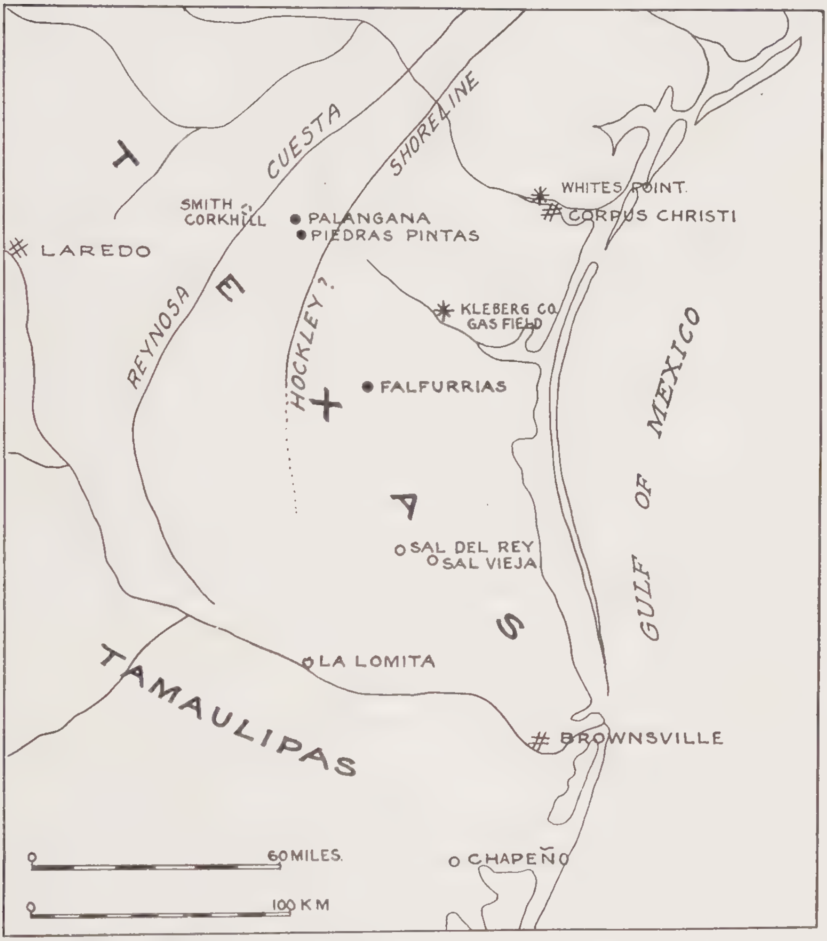

FIG. 1.—Sketch map showing position of the south Texas salt domes

Alva Ellisor, paleontologist of the Humble Oil and Refining Company, for stratigraphic data based on micropaleontological work; to David Donoghue for the data regarding the early history of Piedras Pintas; and to A. G. Wolff of the Texas Gulf Sulphur Company, to the Union Sulphur Company, and to A. H. Smith for the data regarding the development during 1924.

PALANGANA AND PIEDRAS PINTAS

INTRODUCTION

Location.—Palangana and Piedras Pintas are in the east central part of Duval County, about 110 miles due south of San Antonio, and about halfway between Laredo and Corpus Christi. Piedras Pintas lies at Noleda station, about 2 miles north-northeast of the small town of Benavides on the Texas Mexican Railway. Palangana is about 6 miles north of Benavides and 4 miles north-northwest of Piedras Pintas. Both domes are best reached by the Texas Mexican Railway, from Laredo, Robstown, or Corpus Christi to San Diego, which lies 15 miles east of the domes, or to Benavides, or from Laredo, Corpus Christi, or Robstown by automobile. There is a hotel at San Diego, and a railway eating-house with a few beds at Benavides.

History.—The Piedras Pintas shallow oil field is one of the oldest salt-dome oil fields. In August, 1900, a shallow-dug well on the Tinney tract, making a small amount of oil, and a 16-foot well cased with 2-inch pipe, making gas, attracted the attention of A. C. Hall, an oil operator at Corsicana, who leased the area surrounding the wells. In April, 1901, the American Well and Prospecting Company and Guffey and Galey took over the leases and later in the year started a cable-tool test (the Maybee well?). In 1902 the cable tools were replaced by a rotary, and Lawson and Cleary started a well on an adjacent 45-acre tract. In 1903, the Guffey and Galey well was abandoned at a depth of 800 feet; their leases were taken over by the Texas Company; and small production was established on the Lawson and Cleary 45-acre tract. In 1904–5, the Texas Company and the American Well and Prospecting Company deepened the Guffey and Galey well to a depth of 1,506 feet and finally abandoned it 150 feet into the salt. Shows of oil were had at 350, 700, and 1,040 feet and a show of sulphur at 1,000 feet. Desultory exploitation of the shallow productive sands has continued to the present time. In 1917, the Empire Gas and Fuel Company started their deep Becker test, which was finally abandoned in 1921. In 1922, the Humble Oil and Refining Company started deep drilling on the southeast flank of the dome; and during the latter part of 1923 and during 1924, the Union Sulphur Company drilled four tests for sulphur and completed one of them as a small oil well.

Palangana was discovered in 1916 by the Empire Gas and Fuel Company, which drilled its Singer No. 1 in 1916–17. The Sinclair Oil and Gas Company then drilled three wells: Schallert Nos. 1 and 2, which went into the salt on the top of the dome, and Gravis No. 1, three miles east of the dome, which encountered only a normal section. In 1919 the National Oil Company drilled into the salt on top of the dome and then moved eastward with a series of wells, until their No. 4 defined the eastern limit of the salt. Late in 1920, E. F. Simms and Company drilled into the salt on the southern part of the top of the dome and then made a location to the south off the salt for their No. 2. In 1922 the Humble Oil and Refining Company took over the Simms leases, completed the No. 2 well, and drilled three additional wells on the southwest flanks. In 1923 Smith *et al.*, drilling a shallow test on top of the dome, discovered considerable sulphur. In 1924, the Texas Gulf Sulphur Company drilled 25 tests and the Union Sulphur Company 3 tests for sulphur.

PHYSIOGRAPHY

Regional Physiography.—The physiographic province in which the salt domes of south Texas occur is designated as the Gulf coastal plain. In south Texas it consists of the coastal prairie, a flat prairie rising gently from the coast to an abandoned shore which, according to Deussen, runs through Beeville and San Diego; a rolling upland which extends inland from this shore line to the Reynosa (Bordas) escarpment; and a lower plain which rises inland to a more indistinct cuesta. The coastal prairie in general is in extreme youth, but near the coast, in the vicinity of Corpus Christi and Kingsville, is broken by deeply re-entrant bays and by considerable dissection. South of Falfurrias there is much minor relief due to wind activity. The coastal prairie is open and grassy near the coast, but elsewhere in south Texas is covered with a dense growth of mesquite, which, however, has grown within the memory of the older inhabitants. The upland surface consists of rolling hills and wide, shallow valleys with a fairly well-organized system of drainage. On account of the semi-arid climate, the streams are intermittent. The Reynosa (Bordas) escarpment is upheld by the limestones and calcareous conglomerates of the Reynosa formation.

Within the upland, there is a subordinate cuesta formed by a phase of the Reynosa. The scarp of this cuesta comes in from the southwest, and south of Benavides bends eastward to become the south scarp of the Santa Gertrudis Valley. A mile (1½ km.) east of Noleda, the north valley scarp bends northward to become the cuesta scarp and takes a northwesterly course concave around the Piedras Pintas dome and convex around the Palangana dome. West of the cuesta scarp, the general level of the hilltops is around 400 feet (120 m.), and that of the valley bottoms is 350–375 feet (105–113 m.) above sea-level. The upland level is around 500 feet (150 m.). In the general vicinity of Palangana and Piedras Pintas, this upland is deeply incised by San Diego and Santa Gertrudis creeks and their tributaries.

Physiography of the Domes.—The salt domes of the coastal group, where surface expression is present, have a surface mound which is very nearly the shape of an inverted washbasin, or of such an inverted basin with a depression in the center. In the case of the interior domes, surface expression takes the form of a ring or rings of hogbacks around a central mound or a central depression.

The surficial expression of the Palangana salt dome is a circular ring of low hills surrounding a central circular basin (Fig. 2). The diameter of the floor of the basin is 8,000 feet (2,400 m.). The diameter of the ring of hills, the crests of which rise 50–80 feet (15–24 m.) above floor of the basin, is 15,000 feet (4,500 m.). On the east and the west, the broad, flat-topped hills of this circular rim slope rather quickly down to the level of the western lowlands. On the northwest, north, and east, they are separated from the uplands of the cuesta by an incomplete ring of valleys concentric with themselves and with the central basin. On the northeast, they slope steeply down into the valley of the Taranchua. The floor of the basin is not

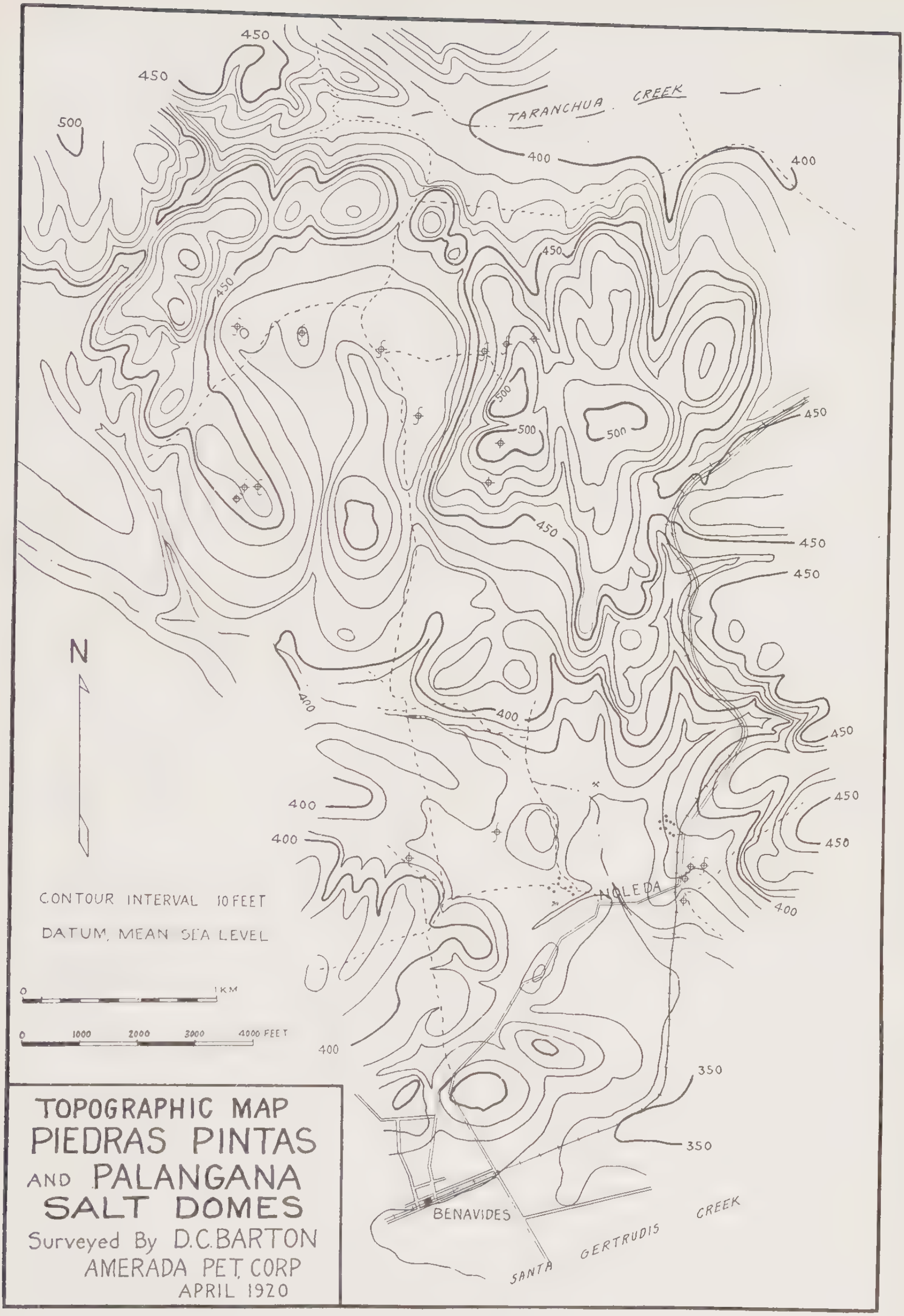

FIG. 2.—Topographic map of Palangana and Piedras Pintas

a simple plain, but is divided on a north-south line through the center by a pair of low, shallow ridges. The basin is drained by a valley which breaches the rim on the southwest and empties into Piedras Pintas Creek.

Three hypotheses can be brought forward to explain the present surficial expression of Palangana: (1) It is the result of the warping of the present general land surface. (2) It is the result of differential erosion of beds already having a domed structure. (3) The central basin is due to collapse of the surface consequent upon the solution of the top of the salt core. This hypothesis is really a modification of either of the two preceding hypotheses.

The evidence favors the second hypothesis in preference to the first. The crest of the hills around the basin are broad and flat-topped, and except where evidently lowered by erosion, rise to the general level of the upland surface to the northwest and the east. From the Empire Gas and Fuel Company's Palangana No. 1 well eastward there is a drop in 6,000 feet (1,800 m.) of only 5 feet (1.5 m.) From the northwest crest northwestward, there is in the same distance no drop, and in a slightly greater distance there is a slight rise. Furthermore, the flat-topped surface of the crests of the rim is separated from the upland surface by valleys which give every evidence of being erosional. This flat-topped surface of the rim seems to be a remnant of the general upland surface. A doming of that surface amounting to 10–15 feet (3–5 m.), or slightly less than the doming of the surface over such salt domes as Hockley and Hull and greater than that over the salt domes at Pierce Junction and North Dayton, might, however, be extremely difficult, if not impossible, of detection on account of the very considerable dissection of this region. As may be seen by reference to Figure 4, the ring of hills owes its existence to the presence of the relatively resistant rock layer which outcrops in them and dips gently away from the dome.

In connection with the third hypothesis, the weight of the evidence would seem to be in favor of the theory of collapse of the underlying beds. In his earlier paper on Palangana, the writer expressed the opinion that "the main evidence against that theory (of collapse) is the absence within most of the basin of the heavy rock like that which caps the rim and is found in the wells on the outer

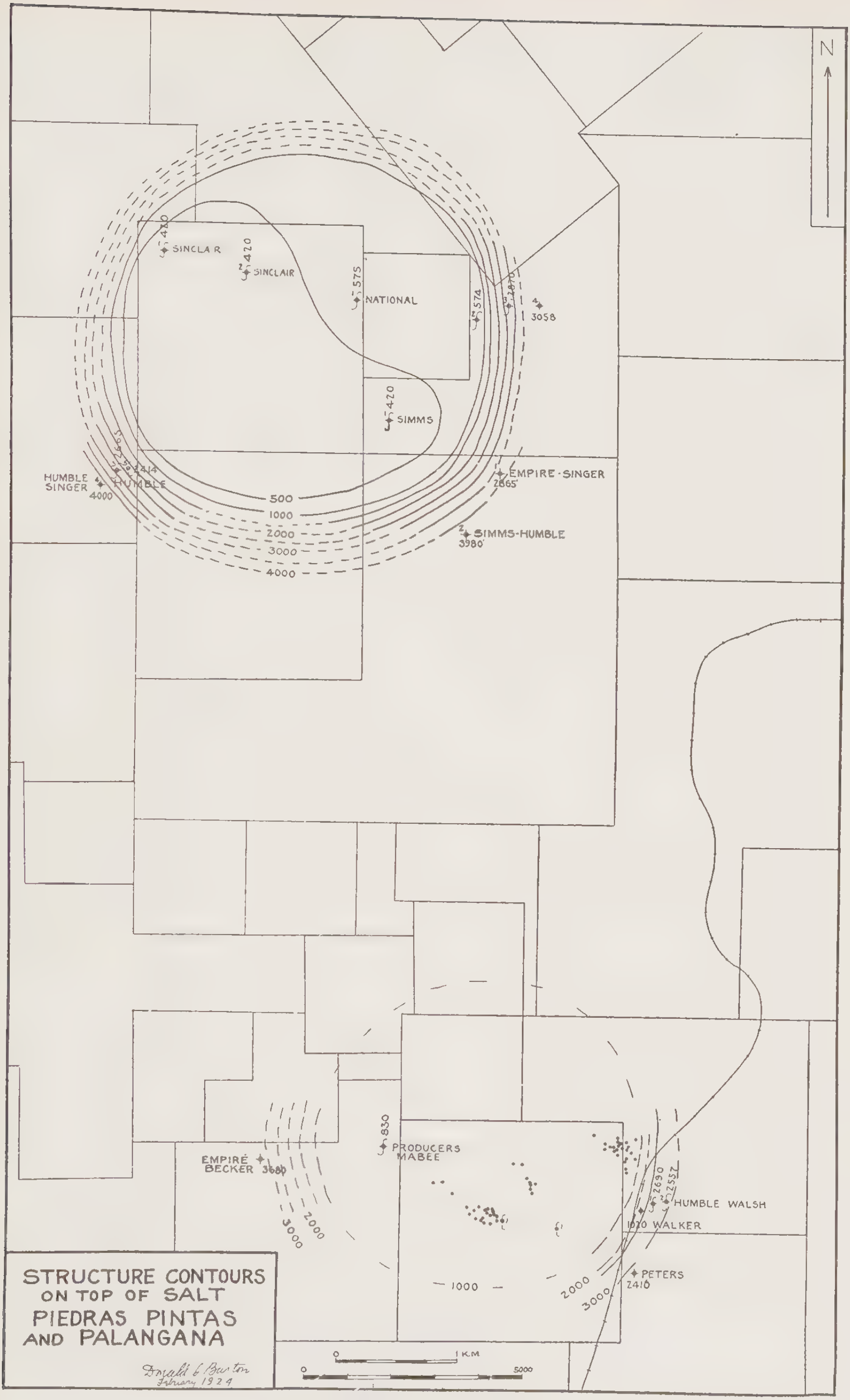

FIG. 3.—Structure and well map of Palangana and Piedras Pintas

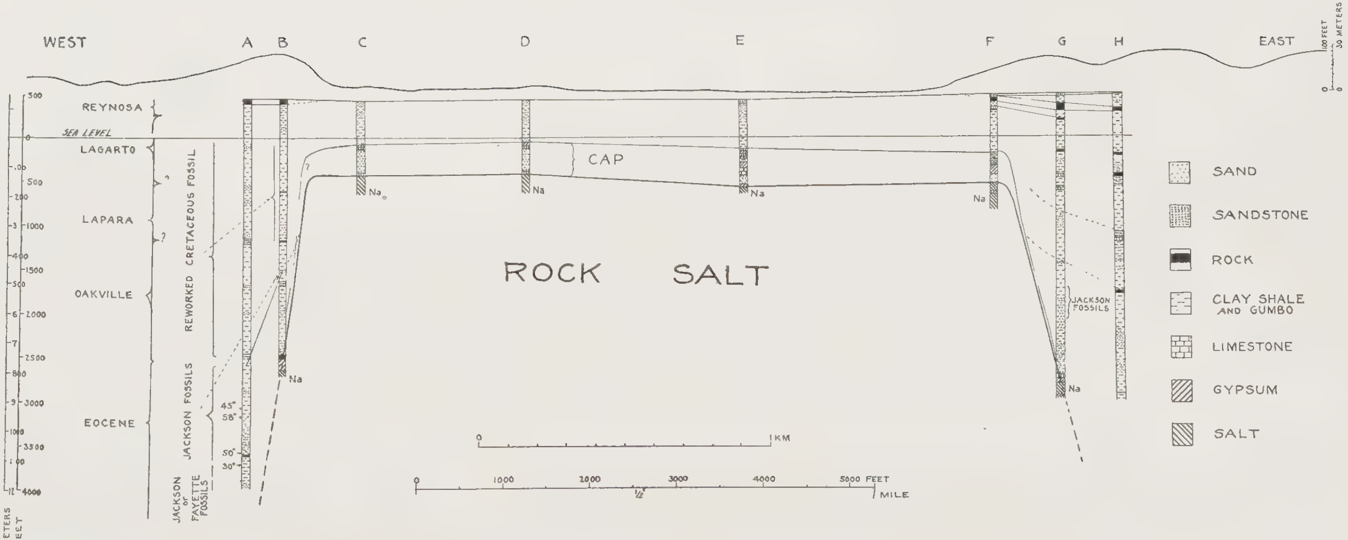

FIG. 4.—West-east Cross-section of Palangana

Scales: vertical = horizontal in geologic section; vertical: horizontal = 5 : 1 in topographic profile. *A*, Humble Oil and Refining Company's Singer No. 4; *B*, No. 2; *C*, Sinclair Oil and Gas Company's Schallert No. 1; *D*, No. 2; *E*, National Oil Company's Schallert No. 1; *F*, No. 2; *G*, No. 3; *H*, No. 4.

edge of the rim and which should be present within the basin if it were due to collapse." That conclusion was based on the logs of the Sinclair Oil and Gas Company's Schallert wells and of National Oil Company's Schallert No. 1, which are now known to give an erroneous picture of the supersalt beds. Massive rock, probably equivalent to the rock capping the rim, was found in most of the Texas Gulf Sulphur Company tests and is very substantial evidence in favor of the formation of the basin by collapse of the subsurface. At a depth of 265 feet (80 m.) in the National Oil Company's Schallert No. 2, very hard siliceous beds were encountered which were reported to have drilled as if dipping steeply toward the dome. As these siliceous beds are due to secondary silicification, they are not necessarily parallel with stratification and their dip toward the basin does not necessarily indicate a general dip into the basin. As the central basin is well drained through the valley which breaches the southwest quadrant of the rim, erosion by stream activity through that valley also would seem competent to have formed the central basin.

The surface expression of the Piedras Pintas dome is extremely indefinite. Piedras Pintas Creek flows across the center of the dome. Over the probable area of the salt, the shallow valley of Piedras Pintas Creek widens to a broad flat, which is roughly circular in outline and is bounded on the east by the hills east of the railroad at Noleda, on the south by the hills south of Noleda village, on the west by the hills near the Empire Gas and Fuel Company's Becker well, and on the north by a low, short ridge about one-third of the way from Noleda village to Palangana. The flat is broken by a low ridge due in large part at least to the presence of a siliceous knob at the surface. The outline of the salt is not known, and therefore the relation of this indistinct basin to the dome is not determinable. As the Humble Oil and Refining Company's Walsh Nos. 1 and 2 seem probably to be on the east edge of the salt, the west slope of the hills east of the railroad at Noleda seems to mark roughly the east edge of the salt. On the west, the Empire Gas and Fuel Company's Becker No. 1 is off the salt, and is back from the eastern slope of the hills near it. This flat is very much larger than the roughly circular small flat basins which are found here and there along most of the creeks of this region, and furthermore, it is of about the same area as the central basin at Palangana. Probably this Noleda flat is the surficial expression of the Piedras Pintas salt dome, but if the salt dome were not known to be present, the topography would hardly lead one to suspect the presence of a dome.

GEOLOGY

Surface Geology.—The Reynosa formation is the characteristic surface formation of the general area around Palangana and Piedras Pintas. It is unconformably overlain by the Lissie gravels (Equus beds), and locally the Lagarto formation is exposed lying unconformably beneath it. The Reynosa is a heterogeneous formation composed of a conglomerate of pebbles of different materials in a calcareous matrix, uncemented gravels, clays, limy sands and sandstones, and tufaceous limestone grading into clays and sands. The Lagarto formation consists of sands and clays which change locally to calcareous sand rock and siliceous or calcareous conglomerate. The Lagarto formation is underlain by the Lapara formation, which consists of interbedded sands and clays carrying porcellanous and flintlike quartzitic material.

At Palangana the crest of the rim is capped by the Reynosa limestone, which also forms all of the hills back of the rim. In Taranchua Creek, Dumble found some sands underlying the Reynosa which seemed to belong to the Lagarto. The rock of the rim has been found within the central basin only in the Simms well at the southern end, where it composed the upper 150 feet of the section. Elsewhere in the central basin, the surface and the upper part of the section in the wells is sand, the age of which is not known; it may belong to the Lagarto or may be part of an older formation which has been brought up by the salt.

At Piedras Pintas, the hills surrounding the Noleda flat are composed of Reynosa limestone. The Noleda flat is covered by a veneer of alluvium. Underlying it is a series of sands and siliceous rocks which outcrop at the base of the surrounding hills, in the knob within the basin, and in the quarries. The name Piedras Pintas, meaning, "Painted Rocks," comes from a group of siliceous rocks covering an area of about 200 square yards (167 sq. m.) and situated 2,000 feet (600 m.) west-southwest of Noleda village. The rocks are a series of coarse and fine sands and of thin shale bands which have undergone varying degrees of silicification. Much of the fine-grained rock is very dense, and looks like a chert. The finest-grained layers are porcelaneous. Many of these are brecciated into sharp, angular, and in some cases splintery fragments, and therefore seem to have acquired their brittleness before the brecciation; but as the cracks between the fragments are filled with coarse sand grains from the overlying or underlying sand beds, the brecciation must have taken place before the silicification of the sands.

A quarry opened to obtain riprap for use at Corpus Christi, is located in the northeast central portion of the Noleda flat, northeast of the central siliceous knob. The quarry is 100 feet (30 m.) long by 40 feet (12 m.) deep. The main bed of siliceous rock is irregular, but averages some 20 feet (6 m.) in thickness. Showing a dip of 30° to 40°, it forms most of the west wall and part of the east wall of the quarry. Above the silicified rock are irregularly bedded sands of varying coarseness and of varying degrees of cementation. Intercalated in the sands are small masses of altered clays which are chalky white, unctuous, impalpible, faintly bitter, and without argillaceous odor. The siliceous rock shows contorted bedding, but varies greatly in character. In some of its phases, it is a quartzitic siliceous sandstone; some very fine-grained material resembles novaculite; other phases are like buhrstone; locally it is chalcedonic. In only one case were the walls of the channels incrusted.

Similar siliceous rock is found in the central knob and in isolated small patches elsewhere around the edges of the Noleda flat. Near the Peters well just south of the Noleda railroad crossing, thin beds of porcelaneous siliceous rock are interbedded in unconsolidated sands. Flinty, quartzitic rock similar to the siliceous rock at Piedras Pintas was found at 60 and 265 feet (18 and 81 m.) in the National Oil Company's No. 2, at Palangana.

The siliceous rocks are due to the deposition in sediments already present of silica from siliceous waters. But the silicification has not taken place recently and seems to have been accomplished before the beds were in their present position. Siliceous knobs occur at several places in the region west of Palangana and Piedras Pintas. Porcelaneous and flintlike quartzitic material is described by

Dumble as occurring in the Lapara. Although the association of the silicified rocks with the salt dome may be suggestive of the genetic association of the hydromineralization with the salt dome, there is no evidence to that effect, and the most probable explanation is that siliceous beds in the Lapara or other formation were uplifted to the surface by the salt.

Subsurface Geology.—Structurally the American salt domes consist of a stocklike core of rock salt with or without a cap of rock, and of beds dipping steeply and quaquaversally from the salt core. The salt core is circular or broadly elliptical in plan, with a diameter of anywhere from ½ to 3½ miles (1 to 5.5 km.); it has nearly vertical sides and a relatively flat top. The cap rock is disklike or thimble-like in form and is composed of anhydrite, gypsum, or limestone, or of all three. Commonly there is a little limestone lying on top of a larger mass of anhydrite-gypsum. The thickness of the cap ranges up to 1,000 feet (300 m.). The dip of the beds on the flanks of the dome varies with the dome, with the depth of the bed, and with the distance from the salt. Dips of more than 45° are common on the deeper beds.

Palangana has the characteristic structure of an American salt dome. The salt core is approximately circular in outline, with a diameter of 11,000 feet (3,300 m.), and has a flat top and very steep flanks. A cap of rock is present which covers the top of the dome and extends well down the flanks. On the flanks of the dome, the lateral sediments dip steeply away from the salt core.

The salt core is delimited on the east by the National Oil Company's wells Nos. 2, 3, and 4, which, respectively, hit the salt at 1,019 feet (310 m.) and 3,347 feet (1,017 m.), and went to below 3,350 feet (1,018 m.) without finding the salt. On the southwest the Humble Oil and Refining Company's wells Singer No. 5 hit the cap rock at 1,951 feet (593 m.); No. 3, cap rock at 2,954 feet (898 m.) and salt at 3,104 feet (944 m.); and No. 4, no cap rock or salt to 4,440 feet (1,350 m.). On the south and southeast Simm's Singer Nos. 1 and 2 and the Empire Gas and Fuel Company's Singer No. 1, respectively, hit salt at 836 feet (254 m.), found no salt or cap rock to 4,407 feet (1,340 m.), and failed to find either salt or cap rock at 3,000 feet (912 m.). On the northwest the Sinclair Oil and Gas Company's

Schallert No. 1 hit the salt at 985 feet (299 m.).[1] From the position of these wells and from the structure contours on the salt in them (Fig. 3), the salt core is proved to be roughly circular in outline and to have a diameter at the top of 11,000 feet (3,350 m.). From the symmetry of the topography, also, the outline of the salt core seems to be circular. The top of the salt is flat; the depths at which it was encountered are 420 feet (128 m.), 420 feet (128 m.), 575 feet (175 m.), 574 feet (174 m.), and 420 feet (128 m.) below sea-level respectively in various wells. The flanks of the salt core are steep; on the east the slope of the salt between the National Oil Company's Nos. 2 and 3 is more than 70°; on the southwest, the slope of the salt between the Humble Oil and Refining Company's Singer Nos. 5 and 3 is probably slightly less than this; but between Nos. 3 and 4, it is more.

The cap was reported in the writer's previous paper on Palangana[2] to be poorly developed. That statement was based on the data then available from the drillers' logs of the Sinclair Oil and Gas Company's Singer Nos. 1 and 2, and the National Oil Company's No. 1, and in the light of information now available seems to have been in error. In Simm's Singer No. 1, the cap was encountered at a depth of 27 feet (8 m.), above sea-level, and 488 feet (148 m.) of solid rock was found. The Humble Oil and Refining Company's Singer No. 5 had over 249 feet (75 m.) of anhydrite, and No. 3 had 150 feet (46 m.) of anhydrite. The National Oil Company's No. 3 had 50 feet (15 m.) of anhydrite above the salt. The four wells, Sinclair Oil and Gas Company's Schallert Nos. 1 and 2, and National Oil Company's Schallert Nos. 1 and 2, logged a thick bed of "lime and gyp" respectively at 60, 60, 145, and 127 feet (18, 18, 44, and 39 m.) below sea-level, and then a series of sand, "rock," "gyp," and "lime," to the salt. In the National Oil Company's Schallert No. 3, cores showed definitely that the drillers' "sand" and "crystallized sand" were anhydrite. As anhydrite is seldom recognized by the Gulf coast driller, but is indiscriminately logged as "crystallized sand," "hard sand," "lime," or "gyp," the writer suspects that there is a thick cap of anhydrite which was not recognized by the drillers on the Sinclair wells and the National wells Nos. 1 and 2. If this is so, there is a cap which extends completely over the top of the dome as well as down the flanks, and has the following thicknesses: on top of the dome, Sinclair Oil and Gas Company's Schallert Nos. 1 and 2, 362 feet (110 m.); National Oil Company's No. 1, 425 feet (129 m.); No. 2, 435 feet (132 m.); Simm's No. 1, 448 feet (136 m.); on the east flank, 50 feet (15 m.) at a depth of 3,300 feet (1,000 m.); on the west flank, 248 feet (75 m.) at 1,900 feet (578 m.) in the Humble Oil and Refining Company's No. 5; and 150 feet (46 m.) at 2,950 feet (897 m.) in No. 3.

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[1] The Texas Gulf Sulphur Company's No. 6, situated 2,000 feet (600 m.) north-northwest of the Sinclair Oil and Gas Company's Schallert No. 1, encountered no cap rock and went directly into the salt at a depth of 1,037 feet, and No. 11, situated 3,600 feet (1,100 m.) north-northeast of the National Oil Company's No. 2, went to a depth of 732 feet (223 m.) without encountering cap rock or salt.

[2] *Bull. Amer. Assoc. Vetrol. Geol.*, Vol. 5, p. 219; *Econ. Geol.*, Vol. 6 (1920), pp. 497–510.

The character of the cap on the top of the dome is known well now as the result of the exploration for sulphur. The section through the cap is shown in Table I. The top of the cap is vague and irregular, and according to Mr. Wolff, of the Texas Gulf Sulphur Company, the upper part of the cap seems to be composed of a mechanical mixture of clay and shale with blocks of the "lime" cap rock and of clay and shale in fissures and caverns in the "lime" cap rock. The only specimen of the "lime" cap rock seen by the writer was composed of oil-soaked medium-grained granular limestone cut by many fissures partially filled by vein calcite (dolomite?). Much of the sulphur is found in the clay and shale and is regarded by Mr. Wolff as residual material left from the solution of the limestone. The gypsum is of the characteristic salt-dome cap-rock type, but showed more evidence of shearing than the writer has seen previously in Gulf Coast cap rock. The anhydrite was not reached in the Texas Gulf Sulphur Company tests and the exact thickness of the

TABLE I

GENERALIZED SECTION THROUGH THE CAP, PALANGANA

	Feet	Meters
Limestone, calcite, clay, and shale..........	520	1.5–6
Limestone, calcite, clay, shale, and sulphur..	3–25	1 –8
Gypsum, at the top a little clay and shale...	100+	30 +
Anhydrite...............................	300—	90 —

gypsum zone is not known. The top of the cap, as nearly as it can be determined, is relatively flat; between the National Oil Company's No. 1 and the northeast edge of the dome, it rises to an elevation of about 100 feet (30 m.) above sea-level and from that area slopes down to an elevation of about 50 feet (15 m.) below sea-level not far in from the edge of the salt on the north and west, and to an elevation of several hundred feet below sea-level in a comparable position in reference to the southwest edge of the salt. The absence of cap rock in the Union Sulphur Company's No. 6 indicates that the cap does not extend continuously down the northwest flank of the salt core; and the presence of the cap in the Humble Oil and Refining Company's Singer Nos. 3, 5, 6, and 7 indicates that the cap extends down the southwest flank of the dome to a depth of at least 3,100 feet (940 m.).

On account of the uncertainty of drillers' identifications, the lithologic character of the cap on top of the dome is not known. On the southwest flank, the section through the cap in the Humble Oil and Refining Company's Singer Nos. 2 and 5 is as shown in Table I. The anhydrite is a fine-grained, dense, hard, deep-blue, well-crystallized rock, characteristic of Gulf Coast salt-dome cap rock. The anhydrite of a core with several solution channels is white. As the cap is relatively thin but steeply dipping, and as only slight lateral movement would be necessary to fault or fold in lateral sediments, the calcareous sandstone logged at 3,005, 3,021, and 3,063 feet (914, 918, 931 m.) does not necessarily belong in the cap-rock mass. The black clay at 3,104 feet (944 m.) is less like the abutting lateral sands, and there is more probability that it is actually included in the cap-rock mass. On the east flank, the cap rock in the National Oil Company's No. 3 is a much more coarsely crystalline, saccharoidal anhydrite. That well went through 130 feet (39.5 m.) of salt and encountered 15 feet (4.5 m.) of similar anhydrite underlain by hard sand, in which the well was abandoned. Sulphur has recently been encountered in considerable quantity in Smith *et al.*, Schallert No. 1 at 390 feet (119 m.).

The steepness with which the lateral sediments dip away from the salt core is distinctly shown in the Humble Oil and Refining Company's wells on the southwest edge of the dome. The contact between the Jackson and the Miocene in their Nos. 3, 4, and 5 was found respectively at 1,228–1,447 feet (373–440 m.), 1,660–2,017 feet (505–613 m.), and 2,950–3,041 feet (897–924 m.). The first number in each case gives the depth of the last sample which could be recognized as Miocene, and the second number the depth of the first sample which could be recognized as Jackson. Cores taken in No. 4 had the following dips: 45° at 3,538 feet (1,076 m.), 58° at 3,588 feet (1,091 m.), 50° at 4,021 feet (1,193 m.), 30° at 4,197 feet (1,245 m.), and 30° at 4,222 feet (1,283 m.).

TABLE II

CORED SECTION THROUGH THE CAP

Depth		Composition of Core
Feet	Meters	
Humble Oil and Refining Company's Singer No. 2		
1,957	595	Galenite with sphalerite and possibly smithsonite veining.
1,959	596	Calcite and a few crystals of anhydrite with smithsonite in veins and cavities.
1,962	597	Calcite, 50 per cent; anhydrite, 50 per cent.
1,968, 1,972, 1,977, 1,982	598	Anhydrite.
1,988	604	Anhydrite with dip of 55°.
1,994, 1,995, 1,998	606–45	Anhydrite.
2,000, 2,003, 2,005		
2,010, 2,018, 2,019		
2,029, 2,035, 2,063		
2,077, 2,080, 2,096		
2,108, 2,121		
Humble Oil and Refining Company's Singer No. 5		
2,984	907	Calcareous, hard sandy clay.
2,986	908	Anhydrite.
3,005	914	Highly calcareous sandy clay.
3,005	914	Anhydrite.
3,021	918	Calcareous sandstones.
3,021	918	Fine-grained dolomitic limestone.
3,040, 3,049, 3,055, 3,061	924–30	Anhydrite.
3,063, 3,068	931–33	Calcareous sandstone with impressions of shells of *Leda*? and *Lucina*.
3,063, 3,084	931–38	Anhydrite.
3,104	944	Black calcareous clay with crystals of salt and anhydrite; fragments of oyster shells replaced by salt.
3,158	960	Anhydrite.
3,180	967	Salt.

On account of the small number of wells that have been drilled on the flanks, the detailed structure of the lateral beds around the salt core cannot be worked out.

Piedras Pintas is a known salt dome and probably has the characteristic form and structure of an American salt dome. The top of the salt lies at a depth of about 1,350 feet (410 m.) below sea-level, but as only one well, the Producers' Oil Company's Mabee well, is known to have been drilled into the top of the salt, its form is not known. Positive control is given on the east by the Humble Oil and Refining Company's Walsh wells Nos. 1 and 2, which found the salt respectively at 2,690 feet (818 m.), and 2,557 feet (777 m.) below sea-level and which, therefore, must be on the east side of the salt. Negative control is given on the southeast by the Peters well, which found no salt or cap to a depth of 2,917 feet (887 m.) below sea-level, and on the west by the Empire Gas and Fuel Company's Becker well, which found no salt or cap to a depth of 3,618 feet (1,100 m.). below the surface. The dip of the flank of the salt core is not known. In the Humble's Walsh wells, there is a slight irregularity in the flank of the salt, as the outer well (No. 2) found the salt 122 feet (37 m.) higher than No. 1.

A cap is present on top of the dome at Piedras Pintas. The four Union Sulphur Company tests for sulphur were located as follows: (see Fig. 3) Tinney No. 1 at the west edge of the southwest group of shallow wells, Saenz No. 1 at the west edge of the central group of wells, Tinney No. 2 east of No. 1 and south of Saenz No. 1, and Canales No. 1 just east of the well with a "C" through the symbol. The log of Tinney No. 1 shows gypsum from 556 to 562 feet and "calcite and lime" from 585 to 625 feet; the log of No. 2, calcareous sandstone, limestone, and shale from 269 to 410 feet, sandy limestone from 410 to 599 feet, gumbo (stiff clay), sandstone, and "lime" from 599 to 1,020 feet, and limestone and gypsum from 1,021 to 1,035 feet; the log of Saenz No. 1, "lime and calcite" from 387 to 619 feet and anhydrite from 619 to 687 feet. Canales No. 1 went to a total depth of 1,028 without encountering any considerable quantity of rock. Much of the "lime," limestone, and sandstone is the result of secondary calcareous cementation and impregnation of previously existing sediments. How much of it, if any, is true "lime" cap rock is impossible to say. None of the few samples seen by the writer were

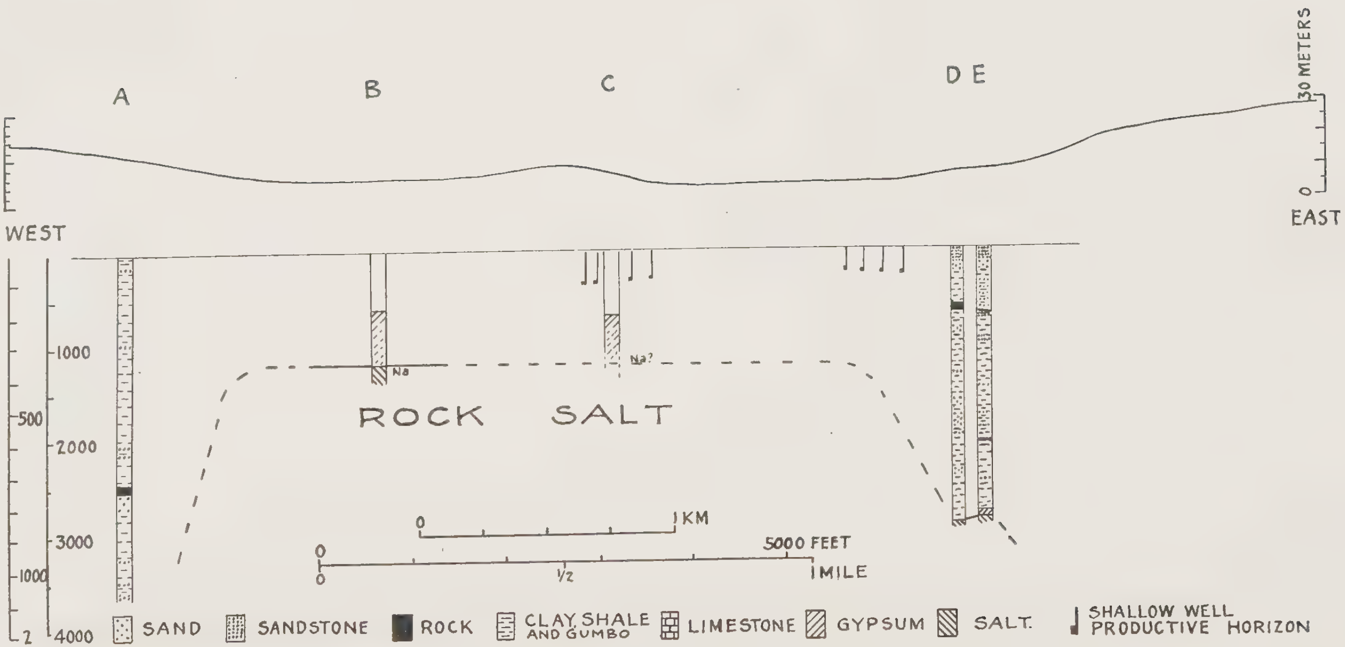

FIG. 5.—West-east cross-section of Piedras Pintas dome

Scales: section, vertical=horizontal; profile, vertical: horizontal=10:1. *A*, Empire Gas and Fuel Company's Becker No. 1; *B*, Producers Oil Company's Maybee No. 1; *C*, Lawton well; *D*, Humble Oil and Refining Company's Walsh No. 1; *E*, Walsh No. 2.

cap rock. The anhydrite is part of the true cap. Its position so much higher in the Saenz No. 1 than in the Tinney No. 2 and the Canales No. 1 and possibly the absence of rock in the Canales well probably indicates very irregular uplift on the top of the dome. The absence in the Canales well of the masses of "lime" rock found in the other wells may be attributable, however, to differences in the conditions of deposition of the secondary calcite. It is possible that the uncommon amount of calcareous cementation in the deeper supersalt beds is genetically connected with the uncommon amount of siliceous cementation in the beds at and near the surface. These data regarding the situation above the top of the salt are vague and unsatisfactory; the correct interpretation of the situation will have to wait on the drilling of a very considerable number of wells through the cap rock.

On the flank in the Humble Oil and Refining Company's Walsh No. 1, no cap rock was found, and in No. 2, only ten feet of anhydrite.

Nothing is known regarding the structure of the lateral beds. In Walsh No. 1, a core at 2,353 feet (925 m.) showed bedding with a dip of 45°, and in Walsh No. 2 a core at 1,782 feet (752 m.) showed a dip of 35°.

Stratigraphy.—The normal stratigraphic section for the region southwest of Brazos River is given in Table III. The section at Palangana as indicated by some of the wells is given in Table IV. At Piedras Pintas, the section as determined by micro-paleontological analysis is as shown in Table V.

The section at Palangana and Piedras Pintas shows great thickening over the normal section for south Texas. As the wells Singer Nos. 3 and 5 and Walsh Nos. 1 and 2 are on the side of the salt, and as Singer No. 4 is very close to the edge of the salt, the beds in them have experienced great uplift. The relative uplift in Singer No. 3 over Singer No. 4 on the reworked Cretaceous-Miocene contact is 700–1,000 feet (210–300 m.), and in Singer No. 5 over Singer No. 4 is 1,570–1,870 feet (498–589 m.). At higher horizons, the uplift is less; on what is tentatively classed as the top of the Oakville, the relative uplift of No. 3 over No. 4 is of the order of 150 feet (45 m.). The absolute uplift cannot be determined from these wells. As the result of the uplift, the section in the wells must have been shortened either through depositional thinning of the beds, thinning by squeezing, faulting out of beds, or erosion. Singer No. 4, being the farthest out from the salt, should have a section nearest the normal, but in spite of the fact that it must have experienced much shortening, the section to the top of the Jackson here shows great thickening. On the basis of lithology, the thickness of the Reynosa in this well is less than 100 feet (30 m.); on the basis of fossils, there is a 90-foot barren zone which is Miocene, Oligocene, or Jackson. If the barren zone is assumed to be Oligocene, and if the maximum thickness of the Lagarto, Lapara, and Oakville are taken, the top of the Jackson

TABLE III

NORMAL STRATIGRAPHIC SECTION

FORMATIONS	DESCRIPTION	THICKNESS	
		Feet	Meters
Pleistocene			
Beaumont clay	Blue calcareous clay with small lime nodules and with lenses of sand and sandy clay.	300– 900	90–270
Lissie gravel	Gravels and coarse sands with pockets of red clay; limy conglomerate south of Guadalupe River.	500–1,000	150–300
Unconformity			
Pliocene(?)			
Reynosa formation	Calcareous conglomerates and limestones with lenses of pink clay.	560–1,500	170–450
Unconformity			
Pliocene			
Lagarto clay	Clays light colored, mottled, with limestone nodules and with sands and sandstones.	345– 645	105–195
Lapara sand	Interbedded sands and clays with clay pebbles and limestone concretions.	75– 455	23–138
Unconformity(?)			
Miocene			
Oakville sandstone	Gray sandstone, soft and hard, calcareous and non-calcareous, with some clay lenses.	180– 600	55–180
Unconformity			
Oligocene			
Catahoula sandstone	Quartzitic sandstones, clays, sandy clays, and sandstones.	0–1,200	0–360
Oligocene in part (?) Eocene, Jackson in part (?)	Clays, marls, limestone, concretions, beds of volcanic ash.	235– 700	70–210
Eocene			
Jackson (?)			
Fayette sandstone	Sands, sandstones, clays, lignite, volcanic ash	480– 800	145–240
Claiborne			
Yegua	Clays, lignite clays, lignite, oyster reefs.	475–1,050	143–315
Cook Mountain	Greensand, greensand marls, iron ore, lignite, clay, sand, and sandstone.	520– 865	155–260

TABLE IV

STRATIGRAPHIC SECTION AT PALANGANA

DEPTH		FORMATION
Feet	Meters	
	Singer No. 4	
Surface	Surface	Reynosa
470–2,950	143– 910	Reworked cretaceous
2,955–3,013	912– 919	Non-fossiliferous cores
3,041–4,187	928–1,277	Jackson
4,274–4,440	1,303–1,354	Jackson or Fayette
	Singer No. 3	
Surface	Surface	Reynosa
520–1,660	158– 506	Reworked cretaceous
1,660–2,017	506– 615	No cores
2,017	615	Jackson
	Singer No. 5	
Surface	Surface	Reynosa
–1,284	– 392	Reworked cretaceous
1,346	410	Non-fossiliferous core
1,447–1,959	441– 597	Jackson

TABLE V

STRATIGRAPHIC SECTION AT PIEDRAS PINTAS

DEPTH		FORMATION
Feet	Meters	
	Walsh No. 1	
Surface	Surface	Reynosa
616– 854	188–260	Reworked Cretaceous
855–2,745	261–837	81 cores taken barren of fossils
2,746–2,872	838–876	Upper Claiborne
	Walsh No. 2	
Surface	Surface	Reynosa
151– 990	46–307	Reworked Cretaceous
990–2,817	307–859	Many cores barren of fossils
2,817–?	859–?	Upper Claiborne

should come at a depth of 1,900 feet (599 m.). It actually comes at 3,041 feet (924 m.). The section above the Jackson shows, therefore, a thickening of 1,150 feet (350 m.), or over 50 per cent. This thickening of the section in the wells over the old "normal" section determined from studies of the formations at their outcrops is characteristic of the Gulf Coast. The actual thickening of the section at Palangana must be very much more than that shown in Singer No. 4, and the actually demonstrated thickening at many places in the Gulf Coast, as, for example, Pine Prairie and Orange, is over 2,000 feet (600 m.). Thickening of the section seaward is, of course, expected, but before the detailed work of the oil geologists in the past three years, the enormous degree of thickening was not suspected. This demonstration of the unexpectedly great thickening of the section shows the danger in extrapolating down the dip seaward, the knowledge gained at the outcrop, and this warning is particularly pertinent in the Palangana–Piedras Pintas region. In his recent studies of the section along the Rio Grande, Trowbridge found no Oakville, Lapara, or Lagarto at the outcrop, and although he mentions the presence of Miocene sediments in the Brownville region, 120 miles (190 km.) south of Palangana–Piedras, and says that the outcrop of the three formations may be hidden under the overlap of the Reynosa, yet the impression given by his discussions warrants no suspicion of over 2,000 feet of Oakville, Lapara, and Lagarto at Palangana–Piedras Pintas, only 30 miles (48 km.) back from the outcrop.

The tentative differentiation of the section above the Jackson is as follows:

The Reynosa formation, on the basis of the reported lithology, is about 55 feet (17 m.) thick in the Humble Oil and Refining Company's Singer Nos. 3, 4, and 5 (Fig. 4); in the National Oil Company's Nos. 3 and 4, it is 40 or 250 feet (12 or 75 m.) thick. The surface rock is Reynosa. The deeper massive rock may be Reynosa or may be a mineralized bed in the Lagarto.

Below the Reynosa, the predominating clayey zone, 850 feet (258 m.) thick in the Humble Oil and Refining Company's Singer No. 4, and 600–650 feet (180–200 m.) thick in the National Oil Company's Nos. 3 and 4, is referred tentatively to the Lagarto.

Below the tentative Lagarto, there is a zone with sand and sandstones in the upper part, and clay in the lower part. In the Humble Oil and Refining Company's No. 4 it is 725 feet (220 m.) thick, and in the National Oil Company's No. 4 it is 500 feet (150 m.) thick. It is tentatively referred to the Lapara.

At 1,600 feet (480 m.) in the Humble Oil and Refining Company's No. 4 and National Oil Company's No. 4, there are several hundred feet of sand, sandstone, and limestone (?). The upper part, composed of alternating clays and gumbos, may belong to the Lapara. The lower part is tentatively referred to the Oakville. The 1,000 feet (300 m.) of clays, sands, and sandy clays below these sands, sandstone, and rock and above the base of the "reworked Cretaceous zone" is referred to the Oakville.

In the Singer No. 4, between the lowermost core which was identified as Miocene and the uppermost core which was identified as Jackson there is a zone 90 feet (27 m.) which was unfossiliferous, and which might be Oligocene. Although well developed in Southeast Texas, the Oligocene wedges out in the outcrop south of the Brazos and is not found at the surface in south Texas, and Oligocene fossils have not been recognized in any of the wells in south Texas. It is very possible, therefore, that Oligocene is missing at Palangana–Piedras Pintas. If present, it can not be over 90 feet (27 m.) thick in Singer No. 4.

A curious feature of the relative stratigraphy of the different wells is that Singer No. 4 had reworked Cretaceous Foraminifera from 470 to 2,950 feet (141 to 900 m.), and that Singer No. 2 and Walsh Nos. 1 and 2 had no reworked Cretaceous Foraminifera below around 1,000 feet (300 m.). As in Walsh No. 1 some eighty-one cores were taken in the barren zone between 855 feet (281 m.) and the top of the Jackson at 2,746 feet (856 m.), there would seem to be no doubt of the absence of the reworked Cretaceous fossils. In the same zone in Singer No. 4, reworked Cretaceous fossils were present in nineteen cores. Just what the significance of their absence may be, is not known. The situation of Singer No. 4 west of the axis of the two domes and the situation of Singer No. 2 and Walsh Nos. 1 and 2 east of the axis suggests that during the Miocene and early Pliocene, the two salt domes had sufficient surface expressions in some way to affect the processes of deposition.

AGE OF THE DOMES

The age of the salt is not known definitely. As it pierces formations as old as Upper Claiborne, it must be older than Upper Claiborne. As, in the interior group of Texas salt domes, it has brought Austin chalk to the surface, the salt there must be at least as old as earlier Upper Cretaceous. As none of the known formations of the early Tertiary or of the Upper Cretaceous has a facies compatible with the formation of salt deposits, the salt of the Gulf Coast domes is probably at least as old as Lower Cretaceous.

The age of the upthrust of the salt is middle Miocene or earlier to late Pliocene or Plio-Pleistocene. The date of the beginning of the upthrust is not determinable As the beds down to a depth of 1,500 feet (457 m.) in Singer Nos. 3 and 4 have only a moderate dip and so do not conform to the steep dip of the top of the Jackson, a part of the upthrust must have taken place at the end, or in the latter part, of the Jackson; and as the Miocene-Jackson contact has been tilted into a dip of some 50° a part of the upthrust must have come since the beginning of the Miocene. As it is impossible to correlate with enough accuracy to determine the amount of the angular unconformity which occurs in or at the end of the Miocene, it is impossible to determine how much upwarping there had been before the early Miocene. The earliest dated upthrust that the writer has observed is at Damon Mound. There an angular unconformity of 15° to 20° between the Oligocene and the Miocene extends out at least ½ mile from the edge of the dome and shows that by the end of Oligocene times there had been greater deformation at the surface than is shown today in any of the Gulf Coast salt domes, and at least as great as is shown at the surface at present by the Palestine and West Point domes. As the amount of uplift which must have taken place by the end of Oligocene is so large, it seems reasonable to suppose that upthrust must have gone well back into the Eocene. The common supposition is that all the salt domes started at about the same time on account of some prevailing condition of tectonic stress. On the basis of this supposition, the beginning of the upthrust would date at least as far back as Eocene times. Although the odds are probably in favor of this supposition, there seems to be no a priori reason why some domes should not have started to form later than others. Whether or not some particular condition of stress was necessary to start the formation of the domes, the forces necessary to the continuation of the upthrust of the domes have continued to the present, and since in some domes, for example North Dayton, there has been no upthrust later than early Pleistocene, and in others, such as Avery's Island, the upthrust probably is continuing today, the forces causing the upthrust seem not to have affected all domes alike. It is entirely possible that in some places there is a slower accumulation than elsewhere of the stresses which result in the upthrust of the salt, and that in those places the formation of the salt domes starts later than elsewhere.

Although the larger part of the upthrust seems to have taken place in Oakville times, the warping of the Lapara, Lagarto, and basal Reynosa indicates that the upthrust persisted into Reynosa times. Notwithstanding uncertainty of correlation, a slightly greater dip in the Lapara and Lagarto indicates that there was movement during Pliocene times. As the present surface shows no appreciable deformation, there has been no determinable uplift since the early Pleistocene or late Pliocene.

ORIGIN OF THE SALT DOME

General statement.—Although in the geological literature in English, the origin of salt domes is still a much-disputed question, the data now available in regard to the German salt domes show with a high degree of scientific certainty that the German domes are the result of plastic yielding to deformation of a sedimentary salt series, and the comparison of these data with those now available for the American, Mexican, and Roumanian salt domes shows that the different types of salt domes are merely the different manifestations which a single general type of structure takes under respectively different regional tectonic conditions.

Origin of the German salt domes.—The proof of the formation of the German salt domes by the plastic flowage of a sedimentary salt series is based on the following evidence:

1) The German Zechstein salt deposits occur in the following structural types: (*a*) Sedimentary beds showing the effects of only slight deformation; (*b*) Stassfurt type salt-dome ridge: low, broad

anticlines with a low, broad salt core tapering gently to each side and with the overlying sedimentary beds gently arched concordantly with the top of the salt (Fig. 6*a*); (*c*) Asse type salt-dome ridge: a narrow, sharp, anticlinal ridge with a narrow, steep-sided, sharply upthrust core of salt and overlying sedimentary beds sharply arched concordantly with the upper surface of the salt (Fig. 6*b*); (*d*) Lower Aller type salt-dome ridge: an anticline with a salt core that projects into or through the overlying sedimentary beds and is in diapir relations to them; the cross-section is the same as the section of a salt stock; (*e*) Hannoverian type salt stock: a circular or elliptical dome with a core of salt which has been intruded into or through the overlying sedimentary beds (Fig. 6*c*).

TABLE VI

STRATIGRAPHIC SECTION IN GERMAN SALT SERIES

Formation	Thickness
"Younger" rock salt	100 feet (30 m.)
"Pegmatic" anhydrite	3 feet (1 m.)
"Red" salt clay	33 feet (10 m.)
"Younger" rock salt	165 feet (50 m.)
"Main" anhydrite	130 feet (40 m.)
"Gray" salt clay	23 feet (7 m.)
"Older" potash series	130 feet (40 m.)
"Older" rock salt	825 feet (250 m.)

2) The section shown in Table VI (after Seidl), with slight variations in character and thickness, can be recognized not only in the essentially undeformed sedimentary beds, but also in all of the different types of the salt domes. The different salt members have different lithologic aspects and can be distinguished. The "Gray" salt clay in places carries a dwarf marine fauna.

3) The different types grade into each other and are manifestly the different reactions of the Zechstein salt series to variations in textonic conditions. In the Magdeburg-Halberstadt Basin, which lies as if crushed between the Flechtinger-Hohenzüg and the Harz pre-Permian massifs, the salt domes take the form of ridges with the same Hercynian strike that characterizes the two massifs. In the North German plain across the northwest end of the basin and the two massifs, the structure of the South Hannover district reflects a

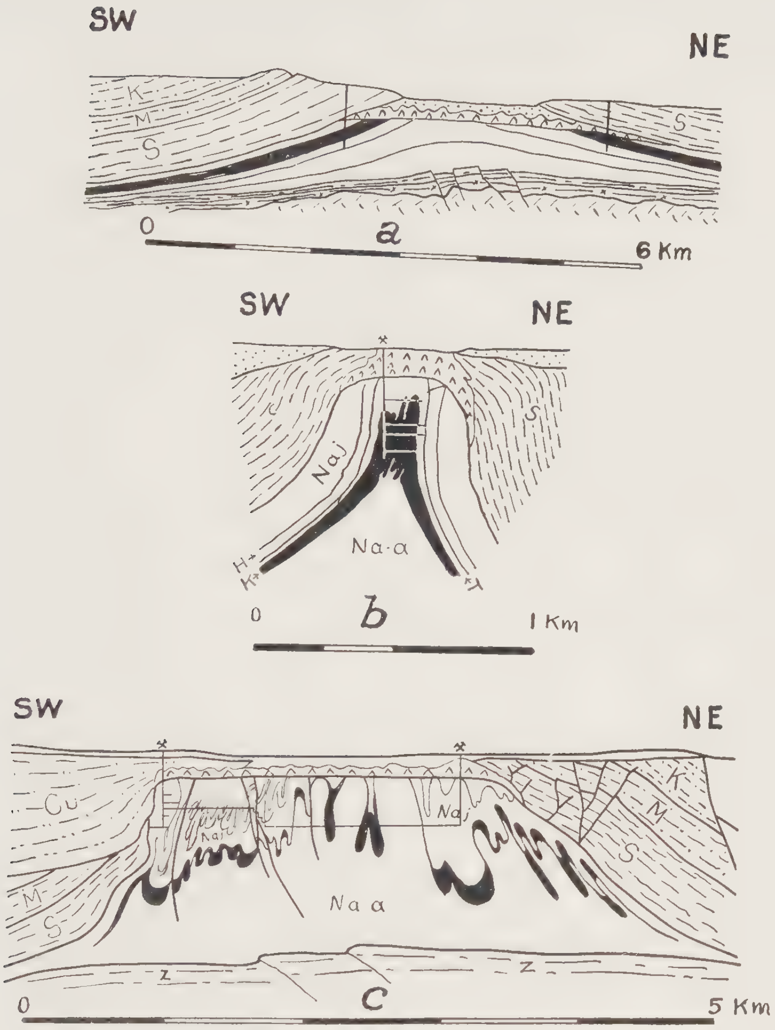

FIG. 6.—Types of German salt domes

a) "Stassfurt" type salt dome ridge, cross-section of the Schmücke-Finne Ridge, after Schlafke.

b) "Asse" type salt dome ridge, cross-section of the Stassfurt Ridge at Wester-Egeln, after Schünemann.

c) "Hannoverian" or "Stock" type of salt dome, cross-section of the Benthe Stock, after Stille and Seidl.

Cu = Lower Cretaceous
K = Keuper
M = Muschelkalk

S = Buntsandstein
Naj = "Younger" salt series
Naa = "Older salt series
∧ = Gypsum cap

Rhenish influence, and in that district the salt domes take the form of salt stocks at the intersections of Hercynian and Rhenish anticlinal axes. In northwestward continuation of the Harz and in the Lower Aller district, the Rhenish influence is not so strongly manifest, and the salt domes tend to take the form of salt-dome ridges striking with the Hercynian axes. Farther north in the North German plain, the salt domes take the form of salt stocks. A general law seems to hold in regard to the form of the cross-section, that where the sedimentary cover is relatively thin, as in the Magdeburg-Halberstadt Basin, the Stassfurt and Asse types with the cover concordant with the upper surface of the salt prevail, and that where the cover is thick, the Hannoverian type prevails, with the salt core in diapir relation to the cover.

4) The abundance of exposures in the potash mines with their galleries at many levels, the data from the borings made in exploration for potash, and the differentiation of the salt series into recognizable members has made it possible to work out the structure of some of the domes in great detail and to demonstrate the great plasticity of the salt.

The genetic connection of the American salt domes with the German as a single type of structure is demonstrated through a study of the German salt stocks, especially through such a dome as the Benthe dome. This is an elongated elliptical dome in which the salt core has steep to nearly vertical sides and has been intruded through beds from Permian to Senonian (Lower Cretaceous), inclusive. Buntsandstein and Muschelkalk have been brought to the surface along the edge of the salt and at the surface can be seen dipping steeply away from the salt core, and at one point are even overturned. Except that the major diameter is two and a half times the minor diameter, in contrast to the equal or subequal diameters of the American salt domes, the outer form and structure of the Benthe dome are identical with those of such domes as Keechi, Palestine, and West Point, and the difference between the aspect of these three domes and the domes of the Gulf is merely due to the presence of a thick column of Neogene to Recent Sediments, which are present along the Gulf Coast but not inland. As the salt cores of the American domes are exposed only in the rather small mines at Avery, Jefferson, and Weeks Islands, the structure has not been determined, but in the Weeks and Avery salt mines, the salt of the American domes exhibits the same plastic folding shown by the salt of the German domes.

The evidence for the formation of salt domes through plastic yielding to deformation is definite and positive. The opposing theories are mostly a priori. They were based on very imperfect knowledge, and are so little applicable to salt domes as they are known today that discussion of them need be entered into only in treating the history of the development of geologic thought in regard to the origin of salt domes.

The recent discovery of mixture of sylvite and halite in a core from 4,800 feet in the Rycade Oil Corporation's Gray No. 1 on the Markham salt dome adds further evidence to the similarity of the American and German salt domes, and the discovery of algae in the salt gives strong evidence in favor of the sedimentary origin of the salt.

Origin of the motive forces.—The motive force causing the deformation is, however, a much more disputed question. The two most probable theories proposed are:

1) That the upthrust of the salt is an isostatic phenomenon due to the (postulated) fact that the salt core is lighter than the stratigraphically overlying sediments. The specific gravity of rock salt is about 2.15. The specific gravity of the uncultivated soils of the Gulf Coast varies from 1.4 to 1.8. The specific gravity of the subsurface sediments is not available, but on the basis of the following argument should not be distinctly greater than that of the salt. The argument is that if the specific gravity of the component minerals is taken, the specific gravity of the sediments averages about 2.6; if an empty pore space of 30 per cent is assumed, the specific gravity is reduced to 1.7; but as the pore space in most cases will be filled with water, the specific gravity should be around 2.0. In the upper part of the section, where the pore space may be greater, the specific gravity should be lower. With increase of depth, there should be increasing compression and density of the sediments. In the case of a salt dome extending down to great depth or in well-compacted sediments, the salt core may be slightly lighter than an equal column of the adja-

cent sediments, but it is a serious question whether the resultant unbalanced force would be sufficient to overcome both the internal friction of the salt and the great friction between the edge of the salt and the adjacent sediments, especially as the surface of contact is large in relation to the mass of salt involved. In such a dome as Sulphur, the anhydrite-gypsum-limestone cap must have a mass density of around 2.7, and should serve to compensate the slight possible deficiency of density of several thousand feet of salt.

2) That the upthrust has been due to lateral thrust. As the salt domes of Old Roumania are involved in the Carpathian thrusts, it is easy to call upon orogenic thrust to account for those salt domes. The German salt domes are at least molded by the old Saxon folding. The anticlinal folds in which the salt domes of the Magdeburg–Halberstadt Basin occur have the form which the sediments of a collapsed or compressed basin would assume. Such a dome as the Benthe salt dome definitely shows the effects of both Hercynian and Rhenish folding. In the case of the American domes, it is much more difficult to call upon thrust. The characteristic circular outline of the domes suggest the absence of compressive thrust from any direction. The region, furthermore, in which they occur has been one of geologic tranquility since Cretaceous times at least, and shows no signs of compressive folding. There were movements which gave rise to the Balcones-Powell–Luling fault system. But the faults seem to be normal faults. In short, there appears to be no good evidence of lateral thrusts in the Gulf Coast area of intensity sufficient to cause the upthrust of our salt domes.

ORIGIN OF THE CAP ROCK

General statement.—The more probable alternative hypotheses for the origin of the cap rock of the American salt domes are: (1) that it is residual material left behind in the solution of the top of the salt core; (2) that it is a secondary deposit resulting from reactions between vadose water coming in contact with the highly saline waters around the salt core; (3) that it is sedimentary anhydrite and limestone which has been caught up and pushed ahead of the rising salt core; (4) that it is sedimentary limestone which has been caught up and pushed ahead of the rising salt column and which has been altered to anhydrite by sulphate waters.

1) *The residual material hypothesis.* The argument for the residual theory rests largely upon analogy with the German salt domes and the theoretic probability that some solution of the salt and collection of the inclosed anhydrite must take place around the upper part of the salt core. This theory is very generally accepted by the German geologists in explanation of the cap rock of the German salt domes and seems to be plausible for them. The salt of those domes contains a notable amount of anhydrite, 5 to 6 per cent in the case of the "older rock salt," in addition to the intercalated beds of anhydrite. Upturned, intercalated beds of anhydrite in some cases, as at Luneburg, can be seen grading into the gypsum cap. The common, very discordant relation of the salt table and the cap to the structure of the salt core in the German domes, as shown, for example, in Figures 6*b* and 6*c*, shows that a large amount of salt has been removed by solution or erosion from the top of the salt core. The cap of the German domes in a general way resembles that of the American domes, but differs from it in that the cap of the German domes grades into a mantle which extends well down the flank of the salt core; that the cap is not composed in part of limestone, that in contrast to the even, uniform, coarsely crystallized selenite, and the massive, even, uniform, saccharoidal anhydrite of the American domes, the gypsum and anhydrite of the German domes have a confused, uneven, and irregular texture

The arguments against the residual theory are: (*a*) that salt of the American domes does not contain as much included anhydrite as the German salt, and practically no intercalated beds of anhydrite; (*b*) that the formation of cap rock of the American type, i e., up to 1,000 feet (300 m.) of homogeneous, even-grained, practically massive anhydrite, by the collection of resdual material is theoretically improbable; (*c*) that the form of the cap-rock mass in most cases is incompatible with formation by the collection of residual material.

a) The argument based upon the apparent lack of sufficient anhydrite in the salt mass is open to considerable question. The character of the salt of the American domes is known best from the salt mines at Weeks, Avery, and Jefferson Islands. But as the absence of cap rock on those domes may reflect the low content of the anhydrite of the salt in those mines, the argument based upon the low anhydrite content there may not be valid for the domes with cap rock. The knowledge of the salt elsewhere on the American domes is very fragmentary and based on scattered, small cores. Few wells are drilled into the salt; most of these are drilled in only far enough to determine that salt has actually been encountered; and in most cases, only one or two cores of the salt are taken. There is, therefore, very little actually known about the salt masses of the domes other than those which contain the salt mines. At the contact of the salt and cap, "salt and gyp" are in many cases reported by drillers. At Brenham, the "salt and gyp" are known to be interbedded salt and anhydrite. The "salt and gyp," however, seem to be confined to the zone just below the top of the salt.

b) The argument for the theoretical improbability of the formation of the cap through the collection of residual anhydrite is as follows:

The great thickness of some of the caps connotes the solution of improbably thick masses of salt. The cap at Sulphur, Louisiana, is 1,000 feet (300 m.) thick. Even if a high estimate of 10 per cent is given for the average calcium-sulphate content of the salt, the formation of the cap at Sulphur would have involved the solution of 10,000 feet (3,050 m.) of rock salt.

It is, of course, probable that if the salt core is exposed to vadose waters, solution and collection of the residual material will take place. But, though the cap as a whole is in many cases cavernous, the anhydrite is in most cases, where the process of alteration to gypsum has not started, a dense, compact rock which should be very slightly pervious and which, once formed, should greatly impede further solution of the salt. If solution did continue, it should take place along solution channels and fissures rather than uniformly over the whole surface of the salt core, and should give rise to slumping and consequent partial brecciation of the cap already formed. The rock finally resulting from such a process expectably would have an irregular texture and structure, if not showing traces of coarse brecciation. But one of the most marked features of the unaltered anhydrite throughout the Gulf Coast and in the domes of northern Louisiana is its even, homogeneous character. Megascopic brecciation is not uncommon in the rock of the cap, but does not involve unaltered anhydrite.

c) The form of the cap in most cases indicates an upthrust origin rather than a residual origin in the present position of the salt. If appreciable solution takes place, it should take place in the upper flanks as well as on the top of the salt, and a resultant residual cap, therefore, should form a thimble-like mantle extending well down the sides. Forms of the cap in the American domes are shown in Figure 7. The cap, in a few cases, does extend down the flanks, but in the majority it is a disklike mass resting on top of the salt, and extending not quite to the edge of the salt.

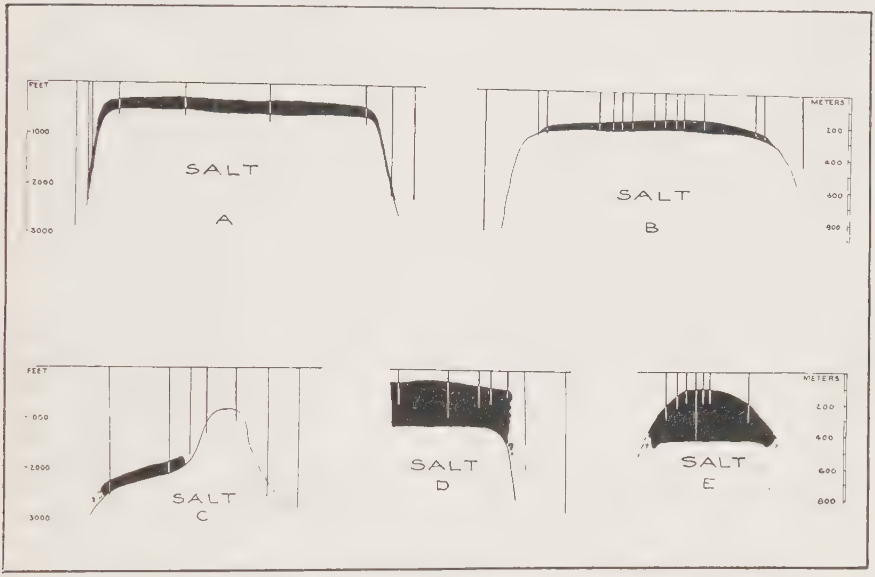

FIG. 7.—Types of cap in the American salt domes

Sections all natural scale. *A*, Palangana; *B*, Bryan Heights; *C*, New Iberia; *D*, East side of Hockley; *E*, Sulphur.

That solution does take place is shown by the central depressions at Anse la Butte, Jefferson Island, and Blue Ridge, but at these domes, the salt comes to within 200 feet (60 m.) of the surface. That the amount of solution on deeper domes is negligible over a very considerable period of geologic time, however, is indicated by the lack of depressions at Big Creek, Stratton Ridge, Pierce Junction, Markham, and North Dayton. These domes are in a late Pleistocene plain. The absence of a distinct mound in each of these cases indicates the absence of distinct upthrust since the late Pleistocene. The absence of a central depression indicates either that solution was just counterbalanced by upthrust, or that the amount of solution since late Pleistocene is negligible.

2) *The secondary-deposit hypothesis.*—The argument for a secondary origin of the anhydrite and gypsum by the precipitation from solution is that calcium sulphate has a maximum solubility of 7.5 grams per liter in solutions of a salinity of 129.5 grams per liter, that the salinity of sulphate-bearing vadose waters is enormously increased at the edge of the salt through solution of salt, and that with increase of salinity above 129.5 grams per liter, the $CaSO_4$ is precipitated as anhydrite at the edge of the salt. Somewhat similar figures have been quoted to show that the gypsum would be precipitated as the concentration of NaCl decreased.

The arguments against such an origin of the anhydrite and gypsum of the cap are:

a) That the normal Gulf Coast waters are poor in sulphates. G. S. Rogers called attention to the fact that in a series of analyses of waters from depths above 1,500 feet (500 m.), he found the average $CaSO_4$ content to be far less than 1 gram, per liter, and the maximum $CaSO_4$ content of any sample to be 2 grams per liter. The writer's experience has been that the deeper waters are similarly poor in $CaSO_4$, or other sulphates.

b) That the precipitation should take place either on the top and upper part of the sides of the core and form a thimble-like mantle, or at the contact of the salt core with a pervious water-bearing stratum, but that in the majority of cases, the flank of the salt core is bare of cap rock, and in a very large number of cases, part or even the whole of the top of the salt core is bare of cap, and that no indication is recognizable of any connection between the cap rock and pervious or impervious beds.

c) That it is difficult to imagine the secondary deposition of the thick masses of anhydrite without inclusion of the sediments in intimate contact with salt. The postulated sulphate-bearing waters must approach the salt along pervious beds, chiefly sands, or along problematic fissures. If precipitation should take place back at least a few feet from the salt in the pervious beds, or the fissures, traces of the original beds should be contained in the anhydrite. But one of the striking characteristics of all the cores of the anhydrite and gypsum that the writer has seen is their uniform purity.

A somewhat similar argument can be made for a similar secondary origin of the limestone of the cap, and there is the additional argument that the calcareous sandstones so characteristic of the Gulf Coast salt domes indicate the secondary deposition of lime in the Oligocene, Miocene, and Pliocene sands around the domes. The "sandrock" and the "rock" logged by drillers from around the domes is in a large number of cases sandstone with a calcareous cement, and at Big Creek conglomerate with a calcareous cement. At West Columbia, the amount of "sandrock" is much greater within 1,000 feet (300 m.) of the salt than it is beyond 2,500 feet (750 m.) out from the edge of the salt.

3) *The uplifted sedimentary beds hypothesis.* The argument for the theory of formation of the cap by upthrust of sedimentary beds is as follows:

a) The form of the cap at many domes indicates that it has been upthrust into its present position. At Bryan Heights, Damon Mound, Hockley, West Columbia, and Spindletop, the cap is a disklike mass of rock that lies directly on the flat salt table, that is several hundred feet (over 100 m.) thick (except at West Columbia), and that stops slightly inside from the edge of the salt. The abruptness of the lateral edge of these thick caps is very striking. A well drilled only some 200 feet (60 m.) in from the edge of the salt table will encounter the full thickness of the cap; and a well 200 or 300 feet away, on the edge of the salt table or on the flank of the salt core, will go directly into the salt without encountering the cap. At Vinton, the cap is similar except that it (and the top of the salt) overhang slightly. If the salt core is thought of as a punch being forced up through sediments, that form of the cap is the one which we should expect to be taken by a core of rock carried ahead of such a punch. Sands and clays should yield by stretching and flowage under the pressure of the head of the salt column. Limestone, anhydrite, or other relatively rigid beds should shear above the edge of the salt, and a disk of the limestone or anhydrite should ride on the top of the advancing column of salt.

b) Sedimentary anhydrite is possible in beds as thick or thicker than the anhydrite of the cap. The "main" anhydrite of the German Zechstein salt deposits is 125 feet (40 m.) thick, and the Lower Zechstein anhydrite at the base of the deposits is 250–350 feet (70–100 m.) thick. In the Toyah district of Texas, a diamond drill penetrated a flat-lying Permian gypsum-anhydrite series 1,900 feet (575 m.) thick. The lower 1,200 feet (360 m.) is anhydrite and the upper 700 feet (215 m.) is gypsum. The anhydrite is distinctly and regularly banded with black bands (*Jahresringe?*) about 0.2 inch (4 mm.) apart. It is fine grained and in a rough way resembles the anhydrite of cap rock in the Gulf Coast salt domes.

c) The anhydrite and the salt in many cases seem to be intergrown at the contact of the salt and cap. The data in regard to the situation at the contact in most of the domes are vague. According to the drillers' logs, "sand," "crystallized sand," "gumbo and gyp," and "gumbo" intervene in many domes between the cap and the salt. As previously noted, anhydrite is seldom logged correctly by drillers, and appears in the logs as "sand," "crystallized sand," "gyp," or "lime." When cores and cuttings are obtained from the same depth, the core may show solid anhydrite and cuttings may show "gumbo (or shale) and gyp." It is, therefore, certain that much of the "sand" and "gumbo" logged from within the cap is anhydrite. A study of characteristic logs through the cap on the various domes warrants the tentative conclusion that the anhydrite as a rule lies directly on the salt. It is very common for the upper part of the salt to be logged "salt and gyp." That may mean that the anhydrite is permeated with brine, that the anhydrite is permeated with secondary salt, that anhydrite cuttings become mixed with the salt cuttings, or that the salt and anhydrite are interbedded. At Brenham, the salt and anhydrite are known from cores to be interbedded and to grade from one into the other. In a well at Brenham drilled by Mr. Fitzsimmons, the upper hundred feet of the salt, from 2,100 to 2,200 feet was composed of interbedded salt and anhydrite. A core from 2,170 feet (658 m.), shown in Figure 8, was composed of alternating bands of anhydrite and salt. The salt is in clear, transparent crystals, 0.5 to 0.8 centimeters in diameter. The anhydrite is the characteristic saccharoidal anhydrite of the cap of the Gulf Coast salt domes. Although the bands are very definite, there is a very uniform gradation at the contact from the salt into the anhydrite. The relative proportions of the salt and anhydrite were estimated to be 55 to 60 per cent salt and 45 to 40 per cent anhydrite. A similar core taken at a depth of 2,110 feet (639 m.) was reported to have consisted of about 40 per cent salt and 60 per cent anhydrite.

d) The limestone which mantles the cap may have been derived from Oligocene limestone, from Upper Cretaceous limestone, or from limestones belonging in the same series as the anhydrite. The presence of thick sedimentary Oligocene limestone on the flanks of Damon Mound suggests distinctly the possibility that it may be the source of the limestone of the cap there. Oligocene limestone is known at other domes, but is reported not to be present everywhere. Although it carries a characteristic fauna, traces of the fossils have not been recognized as yet in the limestone of the cap. The salt may come from formations older than Upper Cretaceous, where there are various limestones which could be carried up by the rising salt mass.

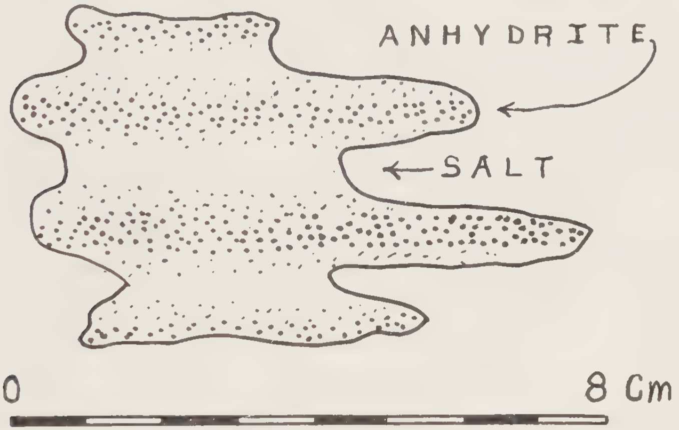

FIG. 8.—Sketch of core of interbedded anhydrite and salt from the Brenham dome

e) The argument against the derivation of the cap through upthrust of sedimentary anhydrite and limestone from lower stratigraphic depths is that the thimble-like cap at Palangana, Pine

Prairie, North Dayton, and some of the other domes, doubtfully could only be formed in such a way. The German potash-salt deposits show very definitely reehuet action of anhydritnder somewhat similar circumstances. The stratigraphic section of those deposits is roughly as shown in Table VII. The "Older" rock salt is more plastic than the overlying members of the series, and in the salt domes and ridges tends to be extruded through them. Unlike the other members of the series, the "Main" anhydrite did not react to the deformation by bending and stretching, but by breaking; commonly it was torn apart wherever the folding was complicated. In the case of Pomes of the Stassfurt type, the "Main" anhydrite is found only in the synclines and on the flanks of the anticlines, and in the Hanoverian type of dome, only in the troughs of the synclines and crests of the anticlines. On the basis of the reaction of the anhydrite in the German domes, it is difficult to see how an anhydrite bed overlying an uprising salt core could be bent into a thimblelike mass intimately capping the salt and extending 1,000 feet (300 m.) down the flanks, and how it could maintain that form and position through thousands of feet of uplift. Much more expectably, the anhydrite should shear off at the edge of the salt, as the Oligocene limestone at Damon Mound apparently did.

TABLE VII.

General Stratigraphic Section of the German Potash Salt Deposits

Formation	Thickness
"Younger" salt series composed of rock salt with minor amounts of anhydrite and clay	200 feet (60 m.)
"Main" anhydrite	130 feet (40 m.)
Potash beds	100 feet (30 m.)
"Older" rock salt	820 feet (250 m.)

4) *The limestone-alteration hypothesis.*—The argument for the derivation of the gypsum and anhydrite of the cap from sulphatization of limestone is based on the known fact that under the action of sulphuretted waters, limestone is altered to gypsum.[1] The anhydrite, however, shows no evidence of being an alteration product; the gypsum shows evidence of being an alteration product only from

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[1] Grabau, A., *Principles of Salt Deposition* (1st edition, 1920), pp. 256–57.

the anhydrite; and in cores showing the contact between limestone and anhydrite, the limestone fills cracks fingering out into the anhydrite or gypsum, and is apparently the younger.

As a result of a priori analysis of the problem, and as a result of detailed study in which sections were drawn through the cap for those domes where sufficient data were available, where the composition of the cap and its relation to the supersalt sediments, the lateral sediments, and the salt were studied, and where a megascopic examination was made of many cores of cap rock, the writer has been able to come to no satisfactory conclusion in regard to the origin of the cap rock of the American salt domes. Before this study was well under way, he tentatively held the theory of secondary deposition, but now considers that the least plausible, and considers most plausible the theory that anhydrite and gypsum are derived from sedimentary beds associated with the original salt beds, and that the limestone in part is derived from sedimentary beds at higher stratigraphic horizons and in part is secondary.

OIL AND GAS

There are three general types of occurrences of oil on a salt dome: in the relatively flat-lying shallow sand lenses above the cap and salt; in the rock and cavities of the cap rock; and in the lateral, steeply dipping, often deeply buried sand lenses on the flank of the dome. The presence of the oil is indicated at the surface in many cases by gas seeps, oil or gas in shallow wells, paraffin dirt, and less often by oil seeps.

At Palangana, none of the surface indications of oil or gas are present. A few of the wells have had shows of oil, but no production has been established. On top of the dome, the Sinclair Oil and Gas Company's No. 2 well had a small show of oil at 398 feet (121 m.). Recently a shallow test of the Autrey Oil Company blew out dark-brown oil and water from about that depth. The Simms No. 1 had a slight show of oil in the cap rock at a depth of 710–782 feet (216–239 m.). On the east flank, in the thick bodies of sand in the lower part of the National Oil Company's Nos. 3 and 4, numerous cores had slight odors of oil. On the southwest flank, in the Humble Oil and Refining Company's Singer No. 3, a core of cap rock was obtained dripping with oil. The Humble's two 4,400-foot (1,338 m.) tests, Singer Nos. 2 and 4, found nothing of interest. Some of the recent sulphur tests had small shows of oil in the top of the cap.

The wells on top of the dome are sufficient to condemn the top of the dome, except for a possibility that wells can be completed which will produce a few barrels of oil per day. The deep dry holes on the south and southwest do not condemn the lateral sands completely, but the chances of future success are poor.

At Piedras Pintas, oil has been produced on top of the dome from shallow depths for a great many years. The field is said to have been discovered through the presence of oil in water wells. At present (January, 1924) there are two small fields about a mile apart. In the eastern field, there are nine wells with a total daily production of 25–50 barrels (3–7 tons) a day. The gravity of the oil is variously reported from 16° to 21° Baumé (sp. gr. 0 96 to 0.93). The oil is said to be about 80 per cent lubricant stock, and about 7 per cent distillate. There are two productive sands, one at 160–180 feet (49–55 m.) below the surface, and the other at 230–324 feet (70–98 m.) below the surface. Structure contours on the lower sand show a moderate dip eastward. The present small productive area has been defined by dry holes on the north, west, and south. The western of the two fields is the older. The field itself and the surrounding territory have been peppered with shallow holes. Most of them had fair shows of oil, many of which could have been made into 1- to 5-barrels-per-day pumpers. Two years ago there were nine producing wells with a total daily production of 25–30 barrels. Some of the wells are said to have come in with a fair initial production, flowing 250 barrels (35 tons) a day for a month. Many of the wells have a long life of 4–8 barrels per day on the pump. The oil is somewhat lighter in color than that of the eastern field, is said to be of 26° Baumé gravity (sp. gr. 0.90), and to have a kerosene content of 40 per cent.

On the flanks there have been several tests, which have had shows of oil but which have failed to establish production. On the west flank, the Empire Gas and Fuel Company's Becker well had shows of 32° Baumé (sp. gr. 0.86) oil and 42° Baumé (sp. gr. 0.81) oil between 3,400 and 3,500 feet (1,034 and 1,064 m.). On the southeast flank, the Peters well had oil shows at 1,300, 1,500, and 2,150 feet (395, 456, and 656 m.). On the east, the Walker well had a good show of oil at 1,291 and 1,337 feet (392 and 406 m.). According to the usual story, each of these wells could have been brought in as a producer if it had been handled properly. The Humble Oil and Refining Company's Walsh No. 1 had a show of oil at 2,896 feet (880 m.) and bailed a little oil at 2,939 feet (893 m.). Their No. 2 had no show worth testing.

FALFURRIAS

INTRODUCTION

The Falfurrias salt dome is one of the very few salt domes of the coastal group in which the cap rock is exposed at the surface, and it is the only one in which the gypsum of the cap rock can be studied directly. The dome has long been known, and was drilled by the Producers' Oil Company in 1911. It goes under various other names, "Las Cuevas," "Gyp Hill," and "Loma Blanca." There has been no drilling since 1911.

Location.—The Falfurrias dome is in the northeastern part of Brooks County, about 7 miles south-southeast of the town of Falfurrias. It is reached by the San Antonio and Arkansas Pass Railroad from San Antonio to Falfurrias, or by the Gulf Coast Lines to Kingsville and automobile to Falfurrias. There is a good hotel at the town of Falfurrias.

Physiography.—The Falfurrias salt dome is on the northern edge of a wind-blown sand area in the coastal prairie. In this general region there is no major relief, but there is a great deal of minor relief due to the presence of innumerable sand dunes, some of them 25 feet high.

At the Falfurrias dome there is Falfurrias Lake, or Laguna Salada, Gyp Hill on the southwest side of the lake, and a hill on the north side. The lake is about 3 miles long by $\frac{3}{4}$ mile wide, and is irregular in shape, with two prongs at the west end and one at the east. The two west prongs mark the enlargement of the mouths of Baluarte Arroyo and Palo Blanco Creek, the east prong, the enlargement of the outflowing creek. Although the western part of the lake half surrounds Gyp Hill, the lake is probably not connected genetically with the salt dome, but is merely a widened stream channel.

Gyp Hill (Fig. 9) is a roughly circular hill with a diameter slightly less than 1 mile and slightly elongated in a north-west-southeast direction. The hill rises 80 feet (24 m.) above the lake and 30–60 feet (9–18 m.) above the general level. The hill on the north side of the lake extends for a considerable distance along the shore of the lake and rises some 20 feet (6 m.) above the general level.

Geology.—Gyp Hill is composed of gypsum, mantled on the lower slopes by wind-blown sands. The gypsum occurs in large crystals 1–8 inches (2–17 cm.) in diameter and 6–18 inches (13–40 cm.) or more in length, the longer axis nearly vertical. Axes of adjacent crystals in most cases are slightly inclined to one another. The crystal form is not expressed, but the various crystals are molded together so that in cross-section they have a roughly hexagonal outline. The crytsals are in layers which are inclined at various low angles and which vary in thickness from a few inches to nearly 2 feet. The prisms of the gypsum are oriented at right angles to the plane of the layer and extend from top to bottom in it. There is a vague tendency for these layers to dip slightly with the hill. In each column there is a tendency for the development of a vertical parting oriented parallel to the tangent to the dome at that point. The gypsum is all in the form of well and coarsely crystallized, fairly clear selenite. Each columnar hexagonal prism is composed of a single crystal. From megascopic examination, the gypsum deposit seems to be very pure.

By far the best exposure of the gypsum is below and south of the crest, in and around an open sink hole which leads into a cave about 10 feet in diameter. The cave slopes downward with the slope of the hill, at an angle of of about 30°, and is large enough to be followed for about 75 feet (25 m.).

Of the subsurface geology little is known. The Producers' Oil Company (the Texas Company) drilled three wells on the southwest slope of Gyp Hill. Two sets of logs are current for the wells. The much more probable set gives the deepest of the wells as drilled 1,000 feet (300 m.) into and abandoned in the "gyp" (gypsum-anhydrite). The less probable set comprises the logs of the three wells drilled respectively to 630, 2,668, and 3,084 feet (192, 811, 938 m.). Some 400 feet (120 m.) of gypsum was logged at the surface, but below

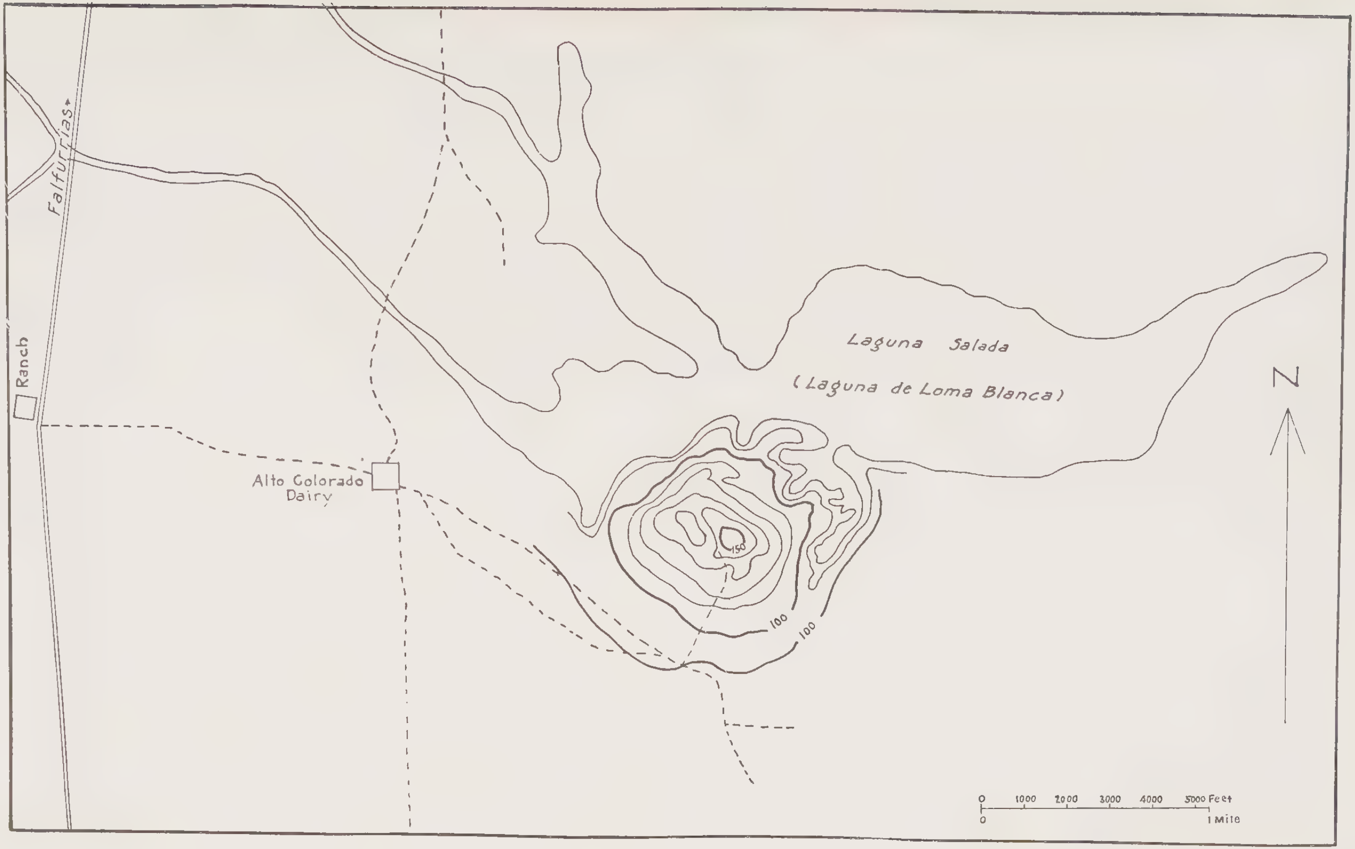

FIG. 9.—Topographic map of the Falfurrias dome

400 feet, little rock was encountered down to 2,830 feet (860 m.) From 2,830 feet to the bottom of the hole, No. 1 had much rock. The amount and distribution of the rock in the section in those wells would be possible for wells drilled through the edge of a slightly overhanging cap rock, such as the one at Vinton. From their position on Gyp Hill, the wells, however, would not be expected to be on the edge of the cap and would not be expected to have the type of section logged in the wells of the second set.

The Falfurrias dome has not been proved definitely to be a salt dome, but on account of the purity of the gypsum mass, the size and shape of the hill, and its position above the general level, Gyp Hill seems to be a salt-dome cap. The size and outline of the probable dome are indeterminate. The chances are that the dome, if present, coincides roughly with Gyp Hill or extends somewhat beyond the imits of this hill. The lake and the hill on the north side of the lake have been interpreted as forming part of the dome. That conclusion does not seem warranted, for the lake appears to be merely a wind-scooped enlargement of the channel of the intermittent stream which flows past the dome. The hill on the north side is probably a dune representing the excavated material.

OIL AND GAS

Surface indications of oil or gas have not been reported at Falfurrias. The only wells which have been drilled near the dome were the Producers' Oil Company Lassater Nos. 1, 2, and 3, all of which were dry. An accumulation of oil in commercial quantity is a possibility at Falfurrias, but the absence in south Texas of known accumulations of oil in commercial quantity in the horizons which could be reached at Falfurrias makes the chance here seem poor. The productive horizons in the Mirando district might conceivably yield oil at Falfurrias. Since, however, the Plio-Miocene section shows a thickening of 2,500–4,000 feet (750–1,200 m.) between the Mirando district and Palangana, since the top of the highest productive horizon in the Mirando district is barely reached at Palangana, and since Falfurrias is about twice as far back from the outcrop of he Plio-Miocene as Palangana those productive horizons are probably deeply buried at Falfurrias. On account of the accumulation of gas at Kingsville, Whites Point, and elsewhere in south Texas, there is a better chance for gas at Falfurrias than for oil.

SAL DEL REY AND SAL VIEJA

INTRODUCTION

Sal del Rey and Sal Vieja are somewhat similar saline lakes west of Raymondville, in Willacy County. Although there is a small export trade in salt from Sal del Rey, and although these lakes have long been points of interest to the Gulf Coast geologists and others, they seem not to have received attention in the literature. They present some evidences of being salt domes and are usually classed as possible salt domes. They have never been proved to be salt domes, and may be merely wind-scooped depressions.

Location.—Sal del Rey is 17 miles (27 km.) west-northwest of the town of Raymondville. It is reached by the Gulf Coast Lines to Raymondville and then by automobile 11 miles (18 km.) due west over the La Coma (MaAllen and Falfurrias) road, and 7 miles (11 km.) northwest over country trails. Sal Vieja is about 7 miles (11 km.) west and 3 miles (5 km.) north of Raymondville. It is reached by automobile from Raymondville over roads and ranch trials.

Physiography.—The region in which Sal del Ray and Sal Vieja lie is the southern equivalent of the flat, featureless, grassy coastal prairie of southeast Texas and southwestern Louisiana. This plain has been much affected by wind activity, and is now a rolling plain of sand dunes, of wind-scooped basins, and of irregular wind-drifted masses of sand, silt, and clay. The region is covered with a dense growth of mesquite.

Sal del Rey is a roughly elliptical lake over 1 mile in length by $\frac{3}{4}$ mile in width (1.5 by 1 km.). It lies in a shallow basin which has no outlet, and no streams flowing into it. It is bounded on the east and north by a nearly flat rolling plain, on the south and southwest by a low ridge rising 10 feet above the plain to the east, and about 20 feet above the general level to the south, on the north-northwest by a faint ridge, and on the west by a shallow depression about one-fourth the size of the main basin. Immediately northwest of the depression is a hill which is the highest point in this vicinity. As this hill lies immediately to the lee of the depression from the prevailing winds and is of approximately of the same size as the depression, the hill and depression are probably due to wind activity.

The size and shape of the basin and the presence of the roughly concentric ridge on the south and southwest are suggestive of a salt-dome mound with central depression. It is more similar to the erosional basin and ring of hills of Palangana than to the deformational mounds and central depressions of the salt domes of the coastal-prairie belt. But Sal del Rey lies in a belt which has not suffered erosion except in the form of superficial wind sculpturing, and therefore should have a deformational mound, if any. Wind-scooped basins are common in this general region, but in no case known to the writer are they as large as Sal del Rey. In some cases the basins are occupied by fresh to brackish, most commonly wet-weather lakes.

Sal Vieja (Fig. 10) consists of two saline lakes lying in a shallow elliptical depression which is $3\frac{3}{4}$ miles long by 2 miles wide, (6 by 3 km.) the major axis trending east-northeast to west-southwest. The western and larger of the two lakes lies in an elliptical basin about 2 miles long by $1\frac{1}{2}$ miles wide (3 by 2.5 km.). It is completely enclosed and has no outlet. At the west end of the basin a fair-sized valley comes in from the west. In the lake, there are four islands rising to within 5 feet of the general level of the surrounding country. The shores of the lake and of the islands show the effects of considerable lateral wave erosion. The bottom of the lake extends very slightly below sea-level. The eastern of the two lakes, sometimes known as Yturria saline, lies in a circular basin with a diameter of about 1 mile (1.5 km.) and with a size about one-half that of the western basin. It is somewhat shallower than the main basin and shows somewhat less lateral wave erosion on the shores. Its bottom lies at about sea-level. Unlike the main basin, it dries up completely in times of drought. The basin is completely enclosed, without outlet or entering streams. The two basins are separated from each other by a flat-topped ridge about 1,500 feet (450 m.) across, which rises about to the general level of the surrounding country.

Sal Vieja is bounded on the northeast, east, and south by the flatly rolling plain of the region, with broad, low, rolling hills rising to a general elevation of about 50 feet above sea-level, and with broad, shallow valleys; on the southwest by a few low hills; and in the northwest quadrant by a distinct range of hills which is ½ mile (1 km.) wide and is concentric with the edge of the lake. The crests of the hills rise about 50 feet (15 m.) above the general level, 70 feet (21 m.) above the lake level, and 85 feet (25 m.) above sea-level.

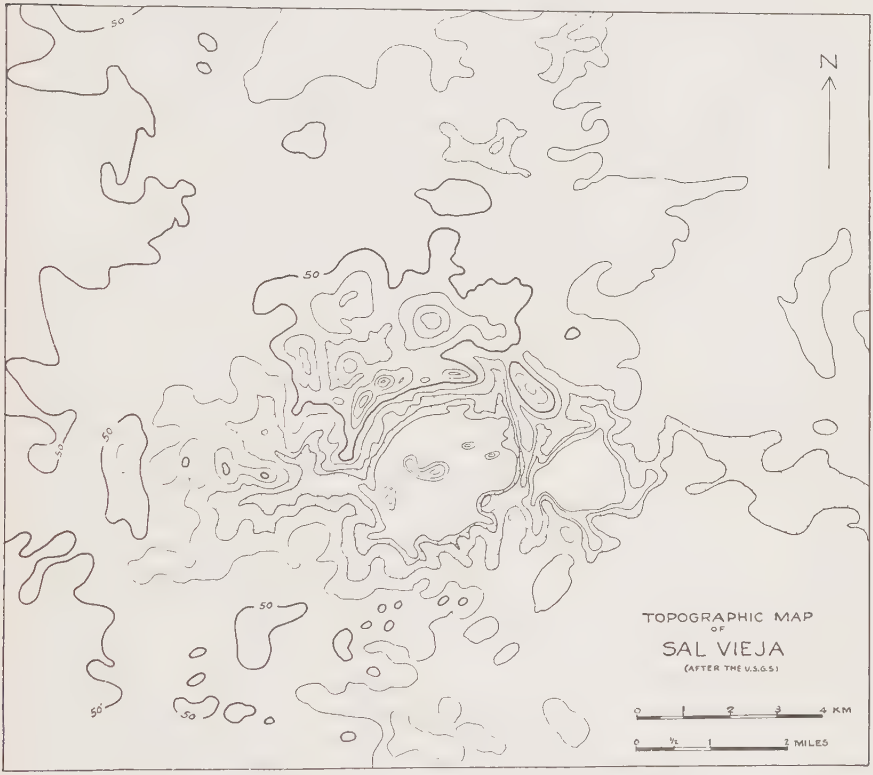

FIG. 10.—Topographic map of Sal Vieja

The form, shape, and size of the Sal Vieja basin and the form and position relative to the basin of the range of hills are suggestive of salt-dome topography, but, as in the case of Sal del Rey, the topography is not quite the deformational type of expression which should characterize a salt dome here. The position of the range of hills on the lee side of the main lake from the prevailing winds, the presence of the islands, and the congruence of the crests of the islands and of the ridge between the two lakes with the general level are suggestive of wind activity as the cause of the basins.

GEOLOGY

The beds which are exposed in the shore-line bluffs of Sal del Rey and Sal Vieja and which normally form the surface of the surrounding region are light-colored clays and sandy clay with some beds of fine sand, which are to be referred either to the Reynosa or the Recent fluviatile deposits. The clay at the surface washes out readily and leaves a sandy soil. Most of the surface is covered by wind-drifted material.

The waters of Sal del Rey, of the main lake at Sal Vieja, and of Yturria Saline are all brines, that at Sal del Rey being notably concentrated. Except after heavy rains, the brine is fully saturated and depositing rock salt. The latter covers the floors of the lake and extends up the beach. According to the accounts of local Mexicans, there is 16 feet (5 m.) of solid salt in the center of the lake. At a point about 25 yards from the center, however, the section shown in Table VIII was found. At times of drought, Sal del Rey dries up completely. The water of Sal Vieja is not so saline as that of Sal del Rey, and the water of the main lake at Sal Vieja is slightly more saline that that of Yturria Saline. In normal seasons, there is a thin salt crust on the beach, but there is no rock salt in the lake; but in times of drought, Yturria Saline dries up completely and a ½-inch layer of rock salt is deposited over the lake bottoms of both Yturria Saline and the main lake. The latter never dries up completely.

TABLE VIII

SECTION THROUGH SALT AT SAL DEL REY

	Thickness
Rock salt	2 inches (5 cm.)
Black clay containing salt crystals	4 inches (10 cm.)
Clear rock salt	3 inches (7.5 cm.)
Black clay	2+ inches (5+ 4 cm.)

Nothing is known of the subsurface geology at either Sal del Rey or Sal Vieja. The nearest well to the former is an 820-foot (250 m.) artesian well three miles (5 km.) east of the lake. At the latter, there is a 1,000-foot (300-m.) water well about 1,000 feet (300 m.) back from the edge of the basin on the Richards ranch. It has a cool, very slightly saline water. One-half mile west of the lake, on the Corbett ranch, is an 800-foot (240-m.) well which has a slightly warm and slightly more saline water. Neither well flows.

A minor feature at Sal del Rey and Sal Vieja is the vesicular texture which the sands of the shores have shown at the times of the writer's visits. The sand had a texture much like that of a very vesicular lava or that of a very thoroughly risen bread. The individual vesicules were rounded and about 0.08–0.12 inches (1.7–2.6 mm.) long by 0.05–0.08 inches (1.1–1.7 mm.) in diameter. Although as a whole the orientation of the longer axes was heterogeneous, there was a tendency to parallelism to the surface. The sand was composed of somewhat irregular, medium-to small-sized grains, in a few cases with a small amount of clayey material. The vesicular sand was found nearly everywhere around Sal del Rey and Sal Vieja between the existing wave-splash line and the foot of the bluffs. It formed a zone 1–2 inches thick about 1 inch below the surface. At the surface there was a crusty layer of sand, in most cases overlain by a film of salt. At Sal Vieja the section shown in Table IX was noted. The area of vesicular sand had been under water three weeks before the time of the writer's first visit. The weather had been extremely hot; maximum temperatures of 112° F. (44° C.) had been registered at a U. S. Weather Bureau Co-operative Observer Station in Raymondville, and the waters of the lakes had evaporated rapidly. The explanation of the vesicular sand may be found in a rapid vaporization of the moisture in the beach sands with consequent simultaneous formation of bubbles and precipitation of the salt in the interstices between the bubbles. The sand grains would be kept at the surface of the bubbles or between them by surface tension and would be cemented together by the precipitated salt to form the walls of the vesicles. As it is dependent on the salt cement, the structure should be rather ephemeral and should crumble before unsaturated brine solutions. But as in one place it survived successive burial by clay, sand, and clay, under favorable conditions the structure might be preserved and be found in the rocks.

Exploitation.—Surface indications of oil and gas are not present at either Sal del Rey or Sal Vieja. No shows of oil or gas are reported from the two water wells drilled near Sal Vieja, and there has been no exploitation for oil at either place.

The salt at Sal del Rey has been worked to a small extent for a great many years by Mexicans. The upper salt crust, which is some 2 to 4 inches thick in the center of the lake, is broken into blocks and is loaded into small wagon trains which come out of Mexico and take it back into the interior. The amount of salt exported is small.

ORIGIN OF SAL DEL REY AND SAL VIEJA

The two most probable possibilities for the origin of the two salines are (1) that they are the surficial expressions of salt domes, or (2) that they are wind-scooped basins in which there has been concentration of surface water.

TABLE IX

SECTION AT THE BEACH, SAL VIEJA

	Thickness (Inches)	Depth (Inches)
Clay	0.3	0–0.3
Vesicular sand	0.5	0.3–0.8
Clay	0.3	0.8–1.1
Vesicular sand	0.5	1.1–1.6

1) The evidence possibly in favor of the first method of origin is: (*a*) the lake basins of the form and size of salt domes, and of considerable resemblance to the central depressions of salt domes; (*b*) the partial, concentric rim of hills on the edge of the basins, roughly similar to the ring of hills around Palangana; (*c*) the concetrated brine and, in the case of Sal del Rey, the salt beds; (*d*) the position of the two salines, which is very closely on the line through Palangana, Piedras Pintas, and Falfurrias. It is strange that with only one line of salt domes known in the whole of south Texas, the only two large salines should lie on this line.

2) The evidence in favor of the second possibility is as follows:

a) Although apparently fulfilling the formula for a salt-dome mound and central depression, the topography is not exactly that of the deformational type of salt-dome mound with a central depression, but is more similar to the erosional type characterized by Palestine and Palangana. But from the position in the coastal prairie, any surficial expression, if present, must be of the deformational type.

b) From the approximate congruence of their crests with the general surface, the islands in the main lake at Sal Vieja and the flat-topped ridge between the main lake and Yturria Saline suggest that they are erosion remnants of the general surface.

c) Formation of the topography through wind activity is distinctly plausible. The area is one of semiaridity; wind action is strong, and sand dunes and wind-scooped basins are common. The prevailing wind is from the southeast, and the distinct rim of hills in each case is in the northwest quadrant.

d) The brine and the salt deposits do not necessarily indicate association with a salt dome. The water of many of the wind-scooped basins of the region is reported to be brackish or briny. Water so salty that the cattle will not drink it is found in abundance at depths of 20 to 50 feet (6 to 15 m.) in the general region around Sal del Rey and Sal Vieja. In view of the very hot, dry weather that prevails, concentration of this salty ground water into brine should take place in any closed basin whose bottom lies below the ground-water level. The formation of the brine at Sal del Rey and Sal Vieja by the concentration of normal surface waters is, however, not an evidence against the salt-dome origin of the topography. If a salt-dome central depression extended below the ground-water level, the concentration would take place similarly to a wind-scooped basin.

e) The presence of potable water at 1,000 feet (300 m.) in the Richards ranch water well on the south edge of Sal Vieja is not preclusive, but is distinctly unfavorable to the hypothesis of the existence of a salt dome beneath Sal Vieja. Waters at that depth from close to a salt dome most commonly are distinctly salty.

A definite conclusion whether or not Sal del Rey and Sal Vieja represent the surface expression of salt domes is not warranted by the evidence available.

OIL AND GAS POSSIBILITIES

If Sal del Rey and Sal Vieja are salt domes, structure favorable for the accumulation of oil is presumably present. On account of the lack of oil or gas seeps around them, and on account of the lack of known commercial accumulation of oil in the coastal section of south Texas, the chance of the existence of commercial pools on or around them is poor. In view of the accumulation of gas at Kingsville, Whites Point, and Three Rivers, there is a better chance for the discovery of gas, but with the absence of gas seeps, even this chance does not seem good.

If Sal del Rey and Sal Vieja are not salt domes, the chance of the existence of oil or gas pools underlying them is only that of acreage chosen at random in this area.

SMITH CORKILL

The Smith Corkill possible salt dome lies 15–20 miles (24–30 km.) west of Benavides in Duval County. The features suggesting the presence of a salt dome are four hills which roughly outline a circle. The hills are composed of chalcedonic and opalized sandstone and of intercalated masses of kaolinized clay. These silicified sandstones and the kaolinized clay are similar to the silicified sandstones and the kaolinized clay at Piedras Pintas. Somewhat similar silicious knobs are found not far to the west and southwest. Smith Corkill may be, but probably is not, a salt dome. There is considerable evidence, according to Deussen, for the presence of a basaltic knob close to these knobs, and he suggests that they may be due to hydrothermal activity of emanations from that volcanic neck.

LA LOMITA

La Lomita, a hill on the Rio Grande, 6½ miles (10.5 km.) south of Mission, is reported by Trowbridge to be a possible salt dome. It is described as a small hill, some 1,600 feet (500 m.) in diameter, rising conspicuously above its alluvial surroundings, and, according to Trowbridge, exposing abnormal materials and abnormal dips, which, however, may not represent true bedding-planes. Three wells are reported to have been drilled on the hill without encountering shows of oil. At least one of the wells was drilled below 3,000 feet (900 m.). The log of one of the wells was examined by the writer and showed nothing indicative of the presence of a salt dome. La Lomita seems probably not to be a salt dome.

CHAPEÑO

Chapeño is about 35 miles south of Brownsville, in the state of Tamaulipas, Mexico. It is usually classed as a possible salt dome. The evidence for the presence of a salt dome is a low swell in the flat, low coastal prairie, with sulphur, sulphur gas, and sulphur water on the top of the swell. It is described in another paper of the symposium.

KINGSVILLE AND WHITES POINT

The Kingsville (Kleberg County) and White Point gas fields are sometimes spoken of as salt domes. As the respective papers on those fields will show, doming is probably present in each, but no evidence of salt-dome formations (salt or cap rock) have been found in the deep wells which have been drilled on them.

They are probably to be classed with the Goose Creek type of structure, which have not been demonstrated to be salt domes.

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CHAPEÑO SALT DOME, TAMAULIPAS, MEXICO

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ABSTRACT

A sulphur deposit in Tamaulipas is described with discussion of its probable relations to a salt dome.

The title of this brief paper is consequent upon the belief of various oil men and geologists that a sulphur deposit located on the Chapeño ranch in Tamaulipas rather definitely signifies the presence of a salt dome. The deposit might better be described under its local name, "Mina de la Pita," signifying the "Maguey Mine,"[1] but, while not expressing final conviction that the deposit does signify a salt dome, the author believes that the sulphur is rather unexplainable upon any other hypothesis.

The "Mina de la Pita" is located on the Chapeño ranch in the northern district of the state of Tamaulipas, in the municipality of Matamoros, 33 miles by air line from the city of Matamoros, 5 miles south of the ranch "San Bartolo," and 1½ miles east of the ranch "Chaparral." It is 5 miles from the Laguna Madre and 15 miles from the Gulf of Mexico.

The deposit is situated in the Gulf coastal plain, the characteristics of which are exactly those of the Gulf coastal plain throughout southeast Texas. The mine itself is located on a very slight elevation, probably a little more than 10 feet above the surrounding flats, the elevation being so small as to be practically imperceptible without the use of levels. Unfortunately, a topographic map of the area is not available.

Just how long the existence of sulphur at this point has been known cannot be learned. The writer's attention was first called to it in 1918, but previous to that it had undoubtedly been known for a long time.

At the time this prospect was visited in 1919, the so-called mine consisted of two or three pits from 5 to 8 feet deep, located on the highest part of the ground. These pits, after passing through the surface soil, composed of about 3 feet of dark clay very strongly impregnated with gypsum, native sulphur, and calcite, entered some 6 feet of blue clay, which contains streaks of free sulphur and many crystals of selenite, and, when freshly exposed, gives off considerable quantities of hydrogen sulphide gas. The gypsum and sulphur appear in larger quantities in the surface soil than they do in the underlying blue clays. Their association in the soil is with a loose, white material, which seems to be a surface deposit in the nature of caliche, and which is undoubtedly calcium carbonate and gypsum. This deposit, although mixed with the surface clays, appears very constantly over an area of 2,000 feet square surrounding the mine. Throughout this area it carries large quantities of sulphur, sufficient in the three pits which the author dug or reopened, to give it a yellow color. Many large pieces were taken from the pit, which contained enough sulphur to support a flame. Gypsum crystals appear in this deposit associated with the sulphur. Investigations outside of the 2,000 feet square area around the mine found the calcareous material not altogether missing under the soil, but in no case were sulphur or gypsum crystals found in it outside of the area adjacent to the mine. An area 2,000 feet square, with the mine roughly in the center, was examined by digging shallow holes down through the soil, and over this whole area sulphur and gypsum crystals were encountered.

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[1] The name probably comes from the fact that maguey plants occur in the vicinity of the mine.

At a distance of about 1,000 feet from the mine there is a well which was drilled in 1907 or 1908. Very salty water stands to the top of the 6-inch casing at the present time, but there is now no remnant from the cuttings from the well. The writer, at the time of his visit, had a log of this well which indicated that it reached a depth of 620 feet, that at this point considerable gas and some oil were encountered, and the well was abandoned. On account of the absence of reliable information about the well, it is probably better to disregard any of the reports concerning it, but it seems fairly certain that it was drilled with a water-well outfit, and accordingly that it was not drilled very deep.

The hypothesis that "Mina de la Pita" is a salt dome seems to be the only one which accounts for the presence of so much sulphur and hydrogen sulphide gas as appear at this point, since other agencies which might give rise to this deposit of sulphur are, so far as we know, totally unknown in the Gulf Coast of Mexico and Texas.

OCCURRENCE OF SULPHUR WATERS IN THE GULF COAST OF TEXAS AND LOUISIANA, AND THEIR SIGNIFICANCE IN LOCATING NEW DOMES

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ABSTRACT

Study of chemical analyses of ground waters in the coast region of Texas and Louisiana indicates that in waters from known salt domes there is a wide variation of sulphur content though higher concentration over the salt core is observed in some cases. Several small ground-water areas unrelated to known salt domes have been distinguished where abnormally high sulphur content is found. These sulphur waters appear to result from surface conditions rather than from buried domes.

For several years the Gulf Production Company has been collecting and analyzing samples of waters from the known salt domes throughout the Coastal Belt of Texas and Louisiana. The object of the work was to determine whether or not waters with high mineral content were of local occurrence over the salt cores of domes, and to compare the results obtained with shallow waters from other localities which appeared to be highly mineralized. Approximately one thousand waters have been analyzed in this work. The samples were for the greater part collected by W. M. Wheless, who performed most of the qualitative tests for hydrogen sulphide, and also compared the analyses of the waters from several wildcat prospects with those of salt dome waters. The quantitative analyses were made in the company's research laboratory in Houston, under the direction of F. M. Seibert and H. E. Minor.

The analyses show that the waters of the known domes vary widely in their sulphur content. At Barber's Hill, for example, a well 37 feet deep and another one 380 feet deep showed practically the same amount of sulphates and hydrogen sulphide; a third well, 150 feet deep, was entirely fresh; at North Dayton, the water in a well 200 feet deep showed sulphuretted hydrogen; another one, 34 feet deep, had a high concentration of sulphates; and another, also

34 feet deep, was entirely free of sulphur compounds. At Goose Creek, sulphur waters occur over an area of more than a hundred square miles. At Cow Bayou, in Orange County, waters containing sulphates and hydrogen sulphide are found far beyond the limits of present production with irregular variation in concentration from the surface down to 600 feet. In the case of Barber's Hill, however, where the areal extent of the salt core has been approximately defined, an average of all the analyses gives a higher concentration over the salt core than the analyses of the waters taken off the salt. But even here, samples taken within a mile of the dome contain a greater percentage of sulphates than most of those from the top of the salt. By a process of averaging, a small area of high concentration can be detected over the salt both at Hockley and Damon Mound, but in the case of the other domes, it is impossible to establish the position of the dome from the occurrence of sulphur waters alone.

In the investigation of waters from localities other than salt domes, several small areas were found which are characterized by an abnormally high percentage of both sulphate and sulphuretted hydrogen. In some instances, shallow waters are as highly impregnated with these constituents as any dome waters that have come to our attention; whereas, all the available waters from deeper sands are quite fresh. Actual drilling of several of these prospects has given no evidence that the sulphur content in these waters is due to a buried dome. Apparently the local concentration at these places is due to some peculiar surface condition.

Geologic investigations show that sulphur waters in the Gulf Coast section of Texas and Louisiana occur in one or more of three, or possibly four, conditions. At Barber's Hill, Hockley, and Damon Mound, they no doubt come directly from the buried domes, since at these places the sulphur content in the water is greater over the dome than it is in the territory immediately surrounding it. Hydrogen sulphide gas occurs abundantly in marshes, lagoons, and swamps throughout the entire coast country, where large amounts of decaying organic matter are found. It is common around the heads of bays, where deposits of such organic matter have been covered with recent sediments. Numerous wells and springs in which the water is derived from sands in contact with such deposits, show this gas. In a few instances, deposits of selenite are apparently the source of both sulphates and sulphides in the water. Finally, it is quite probable that the sulphur water in a number of localities more or less remote from known salt domes has the same source as the deep waters directly associated with a buried salt core.

To summarize, the occurrence of comparatively shallow waters showing varying concentrations of sulphates and hydrogen sulphide throughout the salt dome belt of Texas and Louisiana, is more or less general. Geological examinations of a number of localities where high concentrations were found over small areas show the mineralization to be due in most instances to surface conditions and not to buried domes. Actual drilling has practically condemned several of the most promising areas, emphasizing the fact that new salt domes are not readily located on the evidence of sulphur water alone. That it becomes increasingly difficult to find additional domes is apparent when we consider that of the forty known domes in the Gulf Coast, thirty-seven were found from 1901 to 1913. Of the other three, two were found in 1917 and one in 1922. Since the discovery in 1917 of the Hager-Martin dome in Sec. 28, T. 9 S., R. 7 E., St. Martin Parish, Louisiana, approximately 675 wildcat wells have been drilled in search of new domes on the coast, involving an expense estimated at $20,000,000, exclusive of the cost of leases and overhead expenses. Yet only one new dome has been found during this period and it has not yet proved profitable commercially as a source of oil.

CHEMICAL RELATION OF SALT DOME WATERS

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ABSTRACT

The chlorine content of ground waters from Louisiana and Texas salt domes has been found useful in identifying the source of the waters and in correlation of water-bearing sands. The amount of chlorine is lowest in the near-surface waters and increases downward, reaching saturation near the salt of shallow cores but in domes of the deep-seated type rising gradually at a rather uniform rate below the 2,000-foot level. In several cases structure of the rocks is clearly suggested by chlorine concentration in ground waters.

Thinking possibly that the analyses of oil-field waters might serve to aid us in the development of the coastal fields, numerous water samples were collected at Edgerly, Louisiana.

Samples from various depths, both within the field and from outlying wells, were analyzed. At first a complete analysis was made of each sample procured, hoping a general chemical change would be noted in the waters as their depth increased, or as they became farther removed from the center of the field. The examination of numerous analyses failed to reveal any marked change in oxidation or reduction. The percentage of carbonates in a water in the same sand stratum varied to some extent, due, probably, to local cementation.

A careful study showed that the salt content remained practically constant in waters of each individual water sand over that portion of the area first covered, where correlation of the sands had been definitely established. With this fact known, samples were secured from every test that developed salt water, regardless of location or depth, and a quantitative analysis made for chlorine only. This simplified the chemical work as it permitted analysis in the field. In a short time sufficient data were obtained to prove that chlorine content is constant in the salt water of each individual sand stratum, varying only .1 or .2 per cent over a distance of one and one-fourth miles over the entire field. It was also observed that the chlorine content increased uniformly between each sand and succeeding deeper water sands.

With this information at hand, it became clear, not only that the salt water could be used as a means of correlation, but that water developed in wells through casing leaks, poor casing seats, faulty seals, etc., could be identified by analysis and the true source of the water determined. In the salt dome fields correlation of the beds is extremely difficult, due to the abrupt thickening and thinning of beds. It is almost impossible to follow any individual sand for any distance, yet the depth of the producing sands remains fairly constant, as though production did not come from an individual sand, but from a zone of numerous sand lenses. Although the sands are not themselves continuous, the salt content of the water remains practically constant for each producing horizon.

The results so far obtained show that the chlorine content of the waters ranges from fresh water near the surface to as high as 6½ per cent of chlorine in sands lying 4,200 feet below the surface, the general average rate of increase being approximately .3 per cent per 100 feet of depth. This rate of increase appears to be uniform only below the 2,000-foot level. This work has been carried on at enough of the Gulf Coast salt domes to show that the relations set forth apply only to domes of the deep-seated type, such as Edgerly, Louisiana, Goose Creek and Orange, Texas, or, in other words, where the producing sands have not been intruded by the cap rock or salt mass. In domes where the salt has penetrated nearly to the surface and has cut through the producing sands, the chlorine content gradually increases to the point of saturation as the water-bearing sand approaches and abuts upon the salt core.

In the Edgerly field four producing sands and samples of salt water taken from these horizons show:

Depth of Sand	Per Cent of Chlorine
2,700 feet	1.9
2,900 feet	2.1
3,000 feet	3.5
3,100 feet	4.1

Samples taken from ten wells producing from the twenty-seven hundred foot sand, and so located that a line joining them extends

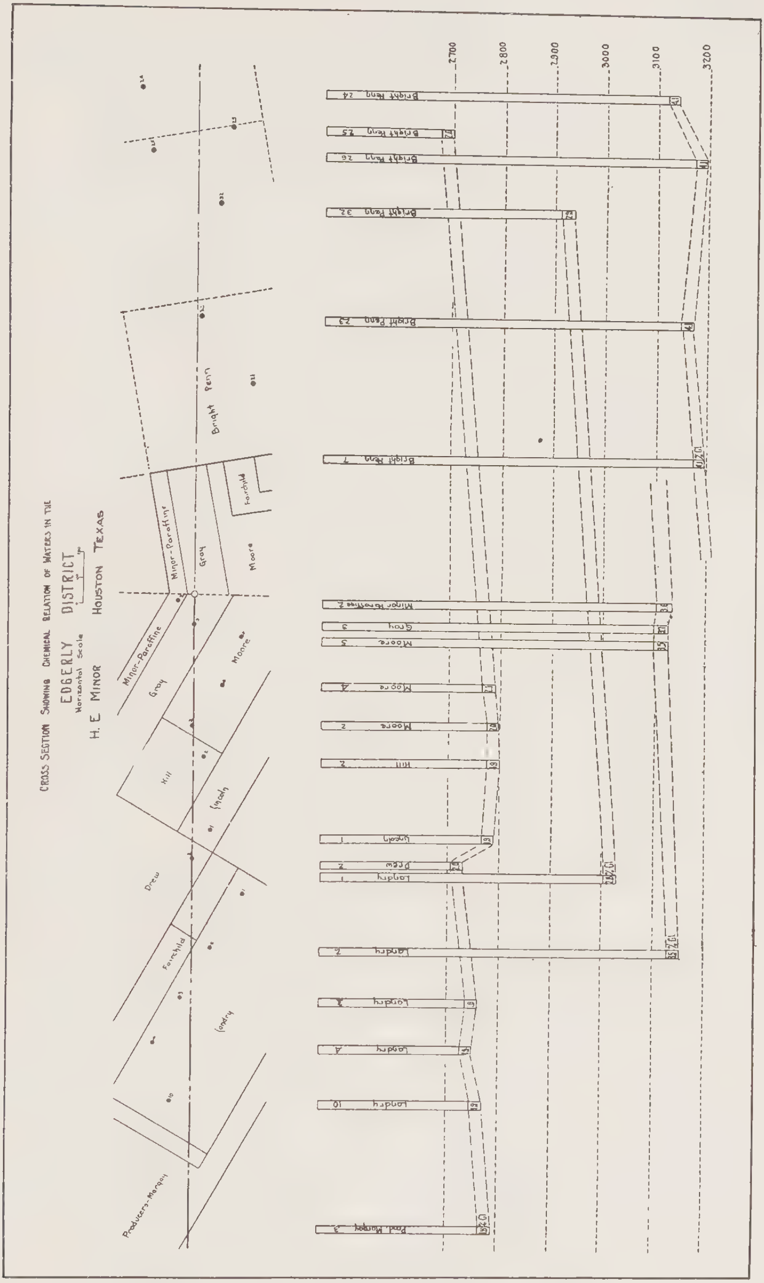
CROSS SECTION SHOWING CHEMICAL RELATION OF WATERS IN THE
EDGERLY DISTRICT
Horizontal Scale
H. E. MINOR HOUSTON TEXAS
2700
2800
2900
3000
3100
3200
Bright Penn 24
Bright Penn 25
Bright Penn 26
Bright Penn 32
Bright Penn 23
Bright Penn 7
Minor Paraffine 2
Gray 3
Moore 5
Moore 4
Moore 2
Hill 2
Lincoln 1
Drew 2
Landry 1
Landry 2
Landry 3
Landry 4
Landry 10
Prod. Marqay 3
Bright Penn
Minor-Paraffine
Gray
Moore
Fairchild
Hill
Lincoln
Drew
Landry
Producers-Marqay

FIG. 1

practically across the field, varied in chlorine content from 1.8 to 1.9 per cent, or a range of only .1 per cent. The accompanying section (Fig. 1) across the Edgerly field shows the uniformity of the chlorine content in the salt water encountered in this sand.

In two of the Gulf Coast fields faults are indicated by the abrupt change in the percentage of chlorine content of waters of equal depth, the downthrown block containing waters less saline than waters found at a corresponding depth on the upthrow side. With sufficient data regarding chlorine content of waters in a field, the amount of displacement of faulted beds might be approximately determined.

In the Goose Creek field conditions are found to be almost identical with those at Edgerly. The analyses of waters from the John Gaillard lease to the Paddock Smith lease, comprising an area 2 miles in length by 700 feet in width, have been plotted. The domed structure of the strata is clearly shown by the chlorine content of the waters (Plate 11).

Upon the map of Goose Creek are shown the lines of equal salt concentration, or what might be called a salt water subsurface contour map. The contours shown are those of a 2 per cent water, and it is interesting to note how closely they conform to the area of actual production. Although some of the largest wells at Goose Creek do not lie within the inner contour, yet the center contour is the approximate center of production (Plate 12).

When these relations are once established in a field, they may be used in many ways. For example: A well at Goose Creek was finished at 3,260 feet, and a screen set from 2,940 feet to 3,060 feet, and from 3,230 feet to 3,260 feet. It produced 4,000 barrels of salt water with a small amount of oil. The water analysis showed 2.2 per cent of chlorine. This chlorine content corresponded to that of 2,900 feet of water. An inside packer was set in the upper screen, cutting off the water and converting the well into a flowing oil well. Geochemical work of this character tends to place geology on a more practical basis and enables the geologist to assist in solving many problems which arise in the development of oil fields.

DISCOVERY OF POTASH SALTS AND FOSSIL ALGAE IN TEXAS SALT DOME

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A core of rock salt containing potassium salts and fossil algae was recently taken, at a depth of 4,800 feet, from Gray No. 1 well of the Rycade Oil Corporation at the Markham, Texas, salt dome. This is the first occurrence of potassium salts reported from the salt domes of the United States, and is probably the most important contribution of fact to a study of their origin for a score of years.

The first appreciable step toward a knowledge of the real structure of the domes was the discovery of the main salt mass of Petite Anse, one of the Five Islands of Louisiana, by the deepening of an old brine well in 1862. We came to know the general form, composition, and structure of our domes as a result of the vigorous drilling campaign which followed close upon the discovery of an oil pool on the Spindletop dome in 1901. The active exploration of the domes since that time, in the mining of oil, sulphur, and salt, has served chiefly to emphasize the essential regularity of the domes, their general conformability to type, and to emphasize the uplift of the overlying and contiguous strata by the formation of the salt core and cap rock of the dome.

The first theories of origin—little more than vague speculations based on entirely inadequate conceptions of the true nature of the domes—regarded them as old Cretaceous outliers in Tertiary seas. With a fairly satisfactory working knowledge of the true constitution of the domes came Robert T. Hill's theory of precipitation of the salt and cap rock from solution in circulating waters. This theory, as elaborated and modified by Gilbert D. Harris with an appeal to the little-understood force exerted by growing crystals as sufficient to account for the uplift of the sedimentary rocks overlying and contiguous to the salt, received wide acceptance among American geologists and is still held by many.

Oil deposits of commercial importance were found in sands deep on the flank of the Humble salt dome in 1913–14; since which time, until quite recently, exploration has been directed chiefly to prospecting the flanks of the domes. The data obtained from such operations stressed the structural effect of dome formation, and salt-dome students began to feel that the Hill-Harris theory of precipitation of the salt cores from solution did not satisfactorily explain the very considerable and highly localized uplift occasioned by the formation of the salt masses. Hahn, as early as 1912, considered the apparent genetic similarity between American salt domes and various European and African salt structures, and Turrentine, in 1913, suggested that some form of the European theory of the formation of salt structures by flow of originally bedded salt under pressure was a theory whose assumptions were less violent than those yet proposed to explain the origin of the American domes. Van der Gracht, in 1917, and Dumble, G. Sherburne Rogers, and the writer, in 1918, expressed themselves in favor of theories of intrusive origin, and some form of such theory has since come generally to be accepted by salt-dome students.

Running through the entire period of our speculations on this interesting subject, however, have been various appeals to volcanism to account for the formation of the domes. These theories of volcanic origin apparently arise from the fact that structurally, a volcanic neck or plug is the only known geological feature which even remotely resembles a salt dome. Lee Hager, Veatch, Clapp, Dumble, Deussen, Oliver B. Hopkins, Lucas, and Washburne have at one time or another expressed themselves as favorably inclined toward theories of volcanic origin. Most of the theories are variations of the solution theories, regarding the salt as precipitated from waters of volcanic origin. Dumble appeals to the same forces which give rise to lava pockets as indicating greater plasticity or mobility in deeply buried bedded salt, variation of the theory of formation of the domes by flow of salt under pressure.

The chief objection to the theories of dome formation by the flow of salt under pressure has been the lack of evidence for the existence of deeply buried bed deposits of salt of sedimentary origin postulated by such theories. The importance of the potash and algae-bearing salt discoveries is that they constitute positive, if not conclusive, proof of the sedimentary origin of the salt of the domes and establish the validity of the theory of the formation of the domes by flow of the salt.

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